OVERHEAD TRANSMISSION LINES AND DISTRIBUTING CIRCUITS

THEIR DESIGN AND CONSTRUCTION

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THEIR DESIGN AND CONSTRUCTION

BY

F. KAPPER

TRANSLATED BY

P. R. FRIEDLAENDER, M.I.E.E.

MEMBER OF THE FACULTY OF ENGINEERING, LONDON UNIVERSITY

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PREFACE

This book is intended to explain the fundamental principles and to give the data essential to the proper carrying out of the very varied operations which fall to the share of the present-day overhead line engineer.

No attempt has been made to provide a complete text-book of structural engineering, so that the calculations have in all cases been carried only as far as seems necessary to cover the direct practical requirements of the designer and constructor of overhead lines.

Especial importance has been given to simplicity of statement, and the numerous worked examples, mostly taken from practice, will prevent any doubt arising in the application of the various formulæ.

The book is based on a practice of many years in this particular branch, and will, it is believed, prove useful not only to the younger engineers but also to those of more experience.

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1. INTRODUCTION

Electricity, which little more than a decade ago was chiefly used for lighting purposes, has been developed technically and economically until it is now one of the most important power transmission agents. Current is now transmitted over hundreds of miles of line at voltages which only a short time ago appeared impracticable. The use of these high voltages has enabled large amounts of energy to be conveyed economically to greater and greater distances from the generating stations.

The recent important advances in electrical engineering, especially the introduction of metal filament lamps and cheaper and more adaptable motors, has ensured the spread of electricity to the country districts.

The reduction in price of current has largely increased the consumption, and, together with the higher economy of modern generating plant and its lower cost, has improved the profit-earning powers of electricity stations, especially of those catering for widespread country districts.

Although the possible applications of electricity in country districts are very numerous and varied, yet the consumption figures can naturally never attain to those of the towns, so that, whilst town supply systems may prove profitable in spite of heavy first cost, to country stations low first cost is essential.

In towns underground cable systems are permissible, but in widespread country districts, with few exceptions, overhead wires alone can be considered.

The modern movement towards the production of electricity in bulk at the coal mine or in the water power station, and its distribution thence over wide areas to both large and small consumers, has given increased importance to overhead lines, and at the same time, with a view to the necessary continuity of supply, has greatly added to the demands made on the designers and builders of such lines. And rightly so. In the generating station stand-by machinery is available which can replace the running machinery, in case of accident, in a few minutes. A skilled *personnel* is constantly on the watch to prevent faults and interruptions from developing, or, at any rate, from affecting the consumers. Further, the machinery in the station is not subjected to the severe atmospheric conditions which affect the overhead line. It is true that every possible provision in case of accident to the line itself is also made. The switching over to a reserve section, however, occupies a certain amount of time. However carefully the inspection of the line is carried out, it still only amounts to a periodic examination of each section, and it is impossible to avoid danger from storms, snow, sleet, birds, etc., and accidents from such causes can only be prevented by the most careful design and mechanical construction.

The cost of the line, as a rule, forms the greater part of the capital cost of a central supply system feeding a widespread country area, and economy in this item will favourably affect the future profits of the station. Of course this economy must not be carried too far so as to affect the continuity of supply and, to a certain extent, the æsthetic effect of the structures. The search for economy should not be in the direction of cheap but unsuitable constructions and materials, but rather towards the careful selection of proved and standardised arrangements. Low first cost is by no means synonymous with low running charges. The expenditure on the repair and maintenance of badly designed installations generally exceeds the interest and sinking fund charges on the more expensive but carefully designed line.

The same point of view applies to the local distributing systems within the villages or small country towns. Here, however, the æsthetic considerations must be given more weight. In the streets, and especially in the main streets, the whole arrangement of the lines and their supports must, as far as possible, be brought into agreement with the spirit of the place. At the same time this idea cannot be carried so far as to make each supporting structure a special and independent design. The construction selected should be such that the separate parts can be employed under the most varied conditions. The size of the stock carried and the delay in procuring materials will then be greatly reduced, and instead of each part being an individual production, repetition work, with its reduced cost, will become available.

The erection of the line, in view of the small margins worked to in modern structures, requires special care and experience. Only conscientious and skilled men, controlled by engineers and inspectors fully conversant with the theory and practice of line construction, should therefore be employed, as this alone will ensure the careful adherence to the rules throughout.

2. MATERIALS FOR THE CONDUCTOR

A MATERIAL suitable for the electric conductor should have a low price combined with a high specific conductivity, low specific gravity, and great mechanical strength. The conductor material must also be considered with regard to its chemical inertness against atmospheric effects and with regard to the ease with which it lends itself to suspension and erection.

The most suitable materials, and those which best satisfy these conditions, are copper and aluminium. For special cases bronze, steel, iron, and "Monnot metal," or copper-clad steel, already much used in America, have been introduced.

TABLE 1.—(*a*) *Copper.*

	Copper Wire.			Remarks.
	Soft.	Medium.	Hard.	
Specific gravity . .	8·9	8·95	8·96	
Breaking stress in lbs. per sq. inch.	31,500—37,000	43,000—51,500	59,000—66,000	The higher values are for wires of ·04 to ·12 inch diameter. For larger sizes the lower values are gradually approached.
Elastic limit in lbs. per sq. inch.	17,000	30,000—38,500	43,000—51,500	
Safe working stress in lbs. per sq. inch.	7,000	14,300—18,500	20,000—26,000	The higher values are for the smaller wires (·04 to ·12 inch). If the wires are stranded into a cable only 90 to 92 per cent. of the load should be allowed.
Modulus of elasticity E in lbs per sq. inch.	$14{\cdot}3\times10^6$	18×10^6	19×10^6	For cables $E_1 = {\cdot}6\,E$ and $\beta_1 = \frac{1}{E_1} = \frac{1}{{\cdot}6\,E}$
Extension coefficient $\beta = \frac{1}{E}$	${\cdot}7\times10^{-7}$	${\cdot}56\times10^{-7}$	${\cdot}53\times10^{-7}$	
Thermal expansion coefficient α.	$1{\cdot}68\times10^{-5}$	$1{\cdot}68\times10^{-5}$	$1{\cdot}68\times10^{-5}$	
Specific conductivity $= \frac{1}{\text{Specific resistance in ohms per inch cube.}}$	$1{\cdot}48\times10^6$	$1{\cdot}46\times10^6$	$1{\cdot}46\times10^6$	

The rules of the Verband Deutscher Electrotechniker allow a working stress of 7,000 lbs. per square inch for soft copper wire and 17,000 lbs. per square inch for hard drawn copper wire. If the breaking stress and the stress producing permanent set are actually determined by tests on samples of the material, a working stress amounting to half the elastic limit stress is allowed, and this latter must itself be 80 per cent. of the breaking stress. Hard drawn copper may only be used in the form of stranded cables made up of wires not exceeding

·12 inch in diameter, since the breaking stress diminishes with increasing diameter. The special advantage of stranded cables over solid wires, besides the greater ease in handling, lies in the fact that damage to the hard surface or a weak place in one of the wires of the cable does not endanger the whole cable.

For hard drawn copper cables the makers will guarantee a breaking stress up to 60,000 lbs. per square inch, the elastic limit being 80 per cent. of this. The allowable working stress would therefore be 24,000 lbs. per square inch. In order to allow for unavoidable errors during erection, however, 21,000 to 23,000 lbs. per square inch should not be exceeded. Hard drawn copper cables are chiefly used for high-tension overhead lines with long spans, whilst for shorter span work, and especially for local overhead distributing circuits, copper of medium hardness is employed. This is used in the form of solid wires up to areas of ·04 square inch, whilst for larger sections stranded cable is preferable. For the thicker wires the guaranteed breaking stress is 43,000 lbs. per square inch, and for stranded cables 47,000 lbs. per square inch. The elastic limit again occurs at 80 per cent. of these figures, so that the allowable safe stress is 17,000 to 19,000 lbs. per square inch, but is usually reduced to 14,000 to 17,000 lbs. per square inch.

Soft annealed copper wire is no longer employed for overhead lines, because the elastic limit is so low that moderate excess loads may lead to excessive extensions, which dangerously increase the sag and necessitate a tightening of the wire.

In local distributing circuits where the supports cannot be unduly strained copper of medium hardness should be selected and worked at a comparatively low tension. Soft copper is still sometimes used as a binding wire for attaching cables to insulators.

TABLE 2.—(*b*) *Aluminium.*

Specific Gravity.	Stress in lbs. per sq. inch.			Modulus of Elasticity E in lbs. per sq. inch.	Extension Coefficient $\beta = \frac{1}{E}$.	Thermal Expansion Coefficient α.	Specific Conductivity per inch cube.	Remarks.
	Breaking.	Elastic Limit.	Working.					
2·7	26,000—29,000	20,000—21,500	13,000	$10{\cdot}5 \times 10^6$	$\cdot 95 \times 10^{-7}$	$2{\cdot}3 \times 10^{-5}$	$\cdot 88 \times 10^6$	The larger values are for wires of ·04 to ·12 inch diameter or cables made up of such wires. For larger diameters the lower values are approached.
	23,000—26,000	18,000—19,500	for cables 10,000	$7{\cdot}7 \times 10^6$	$1{\cdot}3 \times 10^{-7}$	$2{\cdot}3 \times 10^{-5}$	$\cdot 88 \times 10^6$	

The rules of the Verband Deutscher Electrotechniker allow a maximum working load for aluminium of 13,000 lbs. per square inch. The breaking stress is 26,000 to 28,500 lbs. per square inch, and the elastic limit 20,000 to 21,500 lbs. per square inch, whilst the corresponding figures guaranteed by the makers for stranded cables are 21,500 and 17,000 lbs. per square inch respectively.

The safety of erected aluminium lines working at 13,000 lbs. per square inch is

distinctly less than that of a copper line, so that it is advisable not to exceed a load of 10,000 lbs. per square inch, and even then the safety is not equivalent to that of copper lines.

The cross-section of aluminium, for the same conductivity, must be 1·7 times that of copper, so that the stress on sections of equal conductivity in hard drawn copper and in aluminium are 23,000 lbs. per square inch and 10,000 × 1·7 = 17,000 lbs. per square inch. Consequently the loading of terminal and corner masts for aluminium lines are reduced in the ratio of 4 : 3 approximately. The reduced tensile strength and higher expansion coefficient of aluminium, however, necessitate greater sag, so that, especially with the longer spans, the aluminium line involves the use of considerably higher masts. The masts, therefore, generally turn out to be dearer rather than cheaper for the aluminium line.

The greater cross-section of the aluminium wire increases the wind pressure, and this especially affects the intermediate masts between terminal and corner masts, so that these must be considerably strengthened, partly because of the increased force and partly because of the increased height of application of the force. When wooden poles are used and in the case of local distributing networks the aluminium wire may effect economies equivalent to the actual difference in cost between the copper and the aluminium. In these cases the spans are not great, so that the sag, which is proportional to the square of the span, is not appreciably greater than for copper wires and the height of poles need not be increased, consequently the special advantage of aluminium (reduced weight) favourably affects the necessary strength of supports.

One disadvantage of aluminium lies in its softness. The chief strength lies in the hard outer skin, and in order to avoid injuring this special care in erection is necessary. At the same time, owing to the reduced weight, the cost of erection as a whole need not be greater than for other materials.

The low melting point of aluminium increases the danger of breakdown through defective insulators; and another electrical disadvantage is the greater inductance of the line resulting from the greater sag and consequent greater distance between the wires.

The use of solid aluminium wires is no longer recommended by the manufacturers because of the difficulty of insuring sufficient homogeneity in thick wires. Examination of actual breakages showed the formation of glass-hard brittle material at the breaking point; but such occurrences have disappeared since the use of stranded cables has become general.

The price relation of copper and aluminium depends both on the relative conductivities and the relative specific weights. The cross-section of the aluminium must be 1·7 times that of the copper, whilst the two specific gravities are 2·7 and 8·95, consequently for equal total cost :—

$$\text{Copper price} = \text{Aluminium price} \times \frac{2{\cdot}7 \times 1{\cdot}7}{8{\cdot}95}$$
$$= \text{Aluminium price} \times {\cdot}51$$

i.e., the cost will be alike in the two cases if the price of copper per lb. is 51 per cent. of that of aluminium per lb. The curve Fig. 1 shows the saving, or (when

the copper price is less than 51 per cent. of the aluminium price) the loss, effected by the use of aluminium in place of copper.

The difficulty of producing a reliable soldered joint with aluminium has not yet been overcome, so that it is preferable to make joints by means of clamps or sleaves of the same material.

The atmospheric effects are no more troublesome for aluminium than for copper. Alkaline fluids affect it, and certain acids attack it easily with the

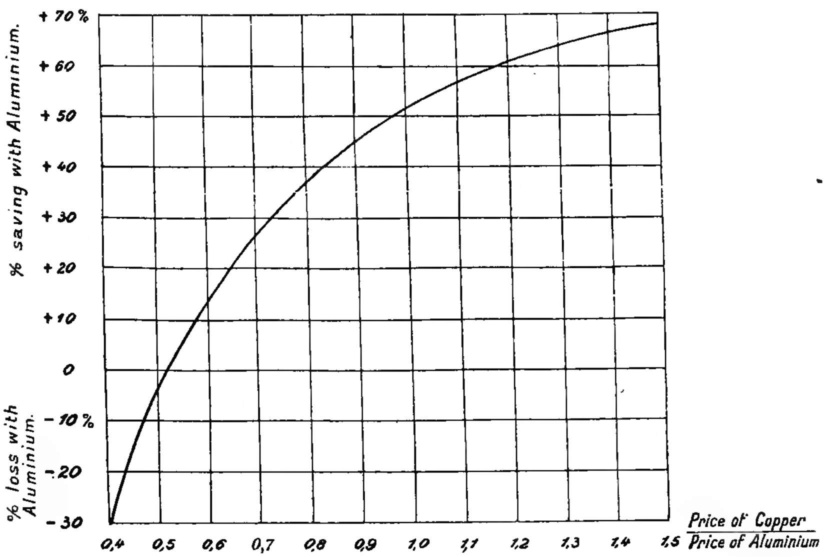


Fig. 1.

evolution of hydrogen. Therefore unprotected aluminium lines are to be avoided in the neighbourhood of chemical works. On the other hand, it has been found that brine-laden sea air affects aluminium less than copper owing to the strongly adherent oxide coating on the former. In the South of France long overhead

TABLE 3.—(c) *Bronze.*

Specific Gravity.	Stress in lbs. per sq. inch. Breaking.	Elastic Limit.	Working.	Modulus of Elasticity E in lbs. per sq. inch.	Extension Coefficient $\beta = \frac{1}{E}$.	Thermal Expansion Coefficient α.	Specific Conductivity per inch cube.	Remarks.
8·92	71,000	49,000	26,000	17×10^6	$\cdot 59 \times 10^{-7}$	$1{\cdot}8 \times 10^{-5}$	$1{\cdot}3 \times 10^6$	For cables $E_1 = \cdot 6\,E$
8·8	100,000	64,000	36,000	17×10^6	$\cdot 59 \times 10^{-7}$	$1{\cdot}8 \times 10^{-5}$	$\cdot 9 \times 10^6$	$\beta_1 = \frac{1}{E_1} = \frac{1}{\cdot 6\,E}$

lines of aluminium run along the sea coast and have shown no signs of deterioration over a long period.

For the longer spans, when the amount of sag is to be limited, bronze is sometimes used. This is an alloy of copper and tin in various proportions to suit different requirements in the way of conductivity and strength. The marked reduction in conductivity with the compositions of greater strength, together with the sensitiveness of the hard material to bending and the consequent

TABLE 4.—(*d*) *Steel.*

Specific Gravity.	Stress in lbs. per square inch.			Modulus of Elasticity E* in lbs. per sq. inch.	Extension Coefficient $\beta = \frac{1}{E}$.	Thermal Expansion Coefficient α.	Specific Conductivity per inch cube.	Remarks.
	Breaking.	Elastic Limit.	Working.					
7·95	100,000	71,000	36,000	27×10^{6}	$\cdot37\times10^{-7}$	$1\cdot2\times10^{-5}$	$\cdot16\times10^{6}$	Steel.
	130,000	100,000	50,000	30×10^{6}	$\cdot333\times10^{-7}$		$\cdot145\times10^{6}$	Cast-steel wire.
	185,000	185,000	71,000	$30\cdot7\times10^{5}$	$\cdot325\times10^{-7}$		$\cdot125\times10^{6}$	Patent cast-steel wire.

* For stranded cables $E_1 = \cdot6\ E$ and $\beta_1 = \frac{1}{E_1} = \frac{1}{\cdot6\ E}$.

increase in the care required for erection, has limited the use of the copper bronzes to special cases.

For very special cases in which very small sags are required with exceptionally long spans galvanised steel wire conductors are sometimes employed. The conductivity is very poor. The maximum permissible conductor area is limited by the strength of the supporting poles. However, the length of the

TABLE 5.—(*e*) *"Monnot metal"* (*Copper-clad Steel*).

Specific Gravity.	Stress in lbs. per sq. inch.			Modulus of Elasticity E in lbs. per sq. inch.	Extension Coefficient. $\beta = \frac{1}{E}$.	Thermal Expansion Coefficient α.	Specific Conductivity per inch cube.	Remarks.
	Breaking.	Elastic Limit.	Working.					
8·45	83,000	67,000	34,500	27×10^{5}	$\cdot37\ \times10^{-7}$	$1\cdot2\times10^{-5}$	$\cdot74\times10^{6}$	For cables $E_1 = \cdot6\,E$ and $\beta_1 = \frac{1}{\cdot6E}$
8·3	128,000	107,000	64,000	30×10^{6}	$\cdot333\times10^{-7}$	$1\cdot2\times10^{-5}$	$\cdot54\times10^{6}$	

steel wire portions of the line are generally so small compared with the whole length of line that the increased ohmic resistance and inductance of these portions are negligible.

The desire to combine the high conductivity of copper with the strength of steel led at a very early stage to the use of steel ropes supporting copper conductors. This construction puts excessive stresses on the poles in the case of long spans, not only because of the increased weight to be carried, but also because of the increased effect of snow, ice, and wind pressure.

TABLE 6.—*Bare Copper and Aluminium Conductors.*

Cross-section.				Number of Single Wires.		Diameter of the Single Wires.				Outer Diameter of Strand.				Weight in lbs. per mile.	
Copper.		Aluminium.				Copper.		Aluminium.		Copper.		Aluminium.			
Sq. mm.	Sq. inch.	Sq. mm.	Sq. inch.	Copper.	Aluminium.	mm.	inch.	mm.	inch.	mm.	inch.	mm.	inch.	Copper.	Aluminium.
6	·0093	—	—	1	—	2·76	·109	—	—	2·76	·109	—	—	190	—
10	·0155	17	·0265	1	7	3·56	·14	1·76	·069	3·56	·14	5·28	·207	320	164
16	·025	27·2	·042	1	7	4·52	·178	2·23	·088	4·52	·178	6·6	·26	510	265
16	·025	27·2	·042	7	7	1·71	·067	2·23	·088	5·1	·2	6·6	·26	520	265
25	·039	42·5	·066	1	19	5·64	·222	1·7	·067	5·64	·222	8·35	·33	800	410
25	·039	42·5	·066	7	19	2·13	·084	1·7	·067	6·4	·252	8·35	·33	820	410
35	·054	59·5	·093	7	19	2·52	·1	2·0	·079	7·7	·304	9·95	·392	1,140	580
50	·078	85	·132	19	19	1·83	·072	2·39	·094	9·2	·362	11·9	·47	1,620	830
70	·108	119	·184	19	19	2·16	·085	2·82	·111	10·9	·44	14·1	·555	2,280	1,150
95	·148	161·5	·25	19	19	2·52	·1	3·3	·13	12·7	·5	16·3	·642	3,100	1,570
120	·186	204	·316	19	37	2·84	·112	2·65	·104	14·3	·562	18·7	·74	3,900	1,990

Attempts were also made in connection with telegraph work to replace plain steel wires by wire of improved conductivity and protected against rust by using steel wires coated with copper. The earlier attempts failed, however, through the difficulty in getting the copper coating to adhere to the steel. Cracks used to occur in the coating, and the subsequent electro-chemical action soon caused the steel to rust through. Recently, however, the Americans have suc-

TABLE 7.—*Insulated Copper Conductors for use when Low-Tension Mains Cross Telegraph Wires.*

Cross-section.		Single Wires.			Outer Diameter of the Insulated Cable.		Gross Weight in lbs.	
			Diameter.					
Sq. mm.	Sq. inch.	Number.	mm.	inch.	mm.	inch.	Per mile.	Per foot.
6	·0093	1	2·76	·109	6	·24	285	·054
10	·0155	1	3·56	·14	7	·28	410	·078
16	·025	1	4·52	·178	8	·32	625	·118
16	·025	7	1·71	·067	8·5	·34	660	·125
25	·039	1	5·64	·222	9	·36	930	·175
25	·039	7	2·13	·084	10	·4	980	·186
35	·054	7	2·52	·1	11·5	·46	1,340	·255
50	·078	19	1·83	·072	13	·51	1,870	·355
70	·108	19	2·16	·085	15	·6	2,570	·49
95	·148	19	2·52	·1	16·5	·65	3,400	·65
120	·186	19	2·84	·112	18	·71	4,300	·82

ceeded in producing in "Monnot metal," or "copper-clad steel," a conductor in which the copper coating is metallurgically welded on to the steel core. A steel block is dipped into molten copper until the outer steel shell becomes alloyed with copper. In order to obtain the required thickness of copper coating the steel block then has a mass of copper cast round it, and the whole is then rolled out into wires of the diameter desired. These bi-metallic wires have come into

TABLE 8.—*Wire Ropes of Galvanised Iron and Steel.*

Wire Material.	Number of Wires.	Diameter of Rope.*		Working load lbs.	Weight per mile lbs.
		mm.	inch.		
Iron . . .	84	3	·118	220	90
Iron . . .	49	3	·118	245	129
Steel . . .	49	3	·118	610	129
Iron . . .	96	5	·197	610	465
Iron . . .	42	5	·197	890	320
Steel . . .	42	5	·197	2,650	320
Iron . . .	72	7	·275	1,330	560
Steel . . .	77	7	·275	4,900	610
Iron . . .	42	9	·355	2,450	1,040
Steel . . .	49	9	·355	6,700	1,160
Iron . . .	42	12	·475	4,900	1,940

* With hemp core.

very general use in America, both for telephone and signalling work and also for power purposes. It has not yet been much taken up on the Continent, although it is a most suitable material for long-span work, as it combines high conductivity with high tensile strength and the capacity to withstand all weather conditions. The fear that cracks would occur or that the copper coating would strip off owing to the unequal expansion coefficients of the two metals has proved to be unfounded. The intermediate alloyed layer appears to equalise the differences successfully.

3. TENSION AND SAG OF THE CONDUCTOR

(1) With Supporting Points at the same Level

A perfectly flexible wire suspended between two fixed points A and B (Fig. 2) assumes, under the action of its own internal and external forces, the form of a catenary curve, the stress on which is at all points proportional to the length. The catenary curve is almost identical with a flat parabola, so that, for simplicity, the equation to the parabola will be used in the following pages.

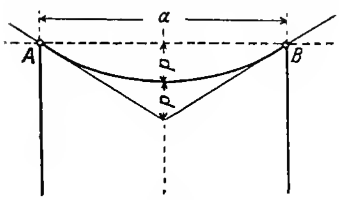


Fig. 2.

When the sag or dip d is very small compared with the span a, as is almost always the case, and when allowance is made for the fact that overhead lines are not perfectly flexible, the error introduced by this simplification is negligible. (For the exact treatment see Keil, " Elektrotechnischer Anzeiger," 1911, Parts 63, etc.)

The forces being balanced as in Fig. 3, the following relations hold :

$$s \, . \, d = \tfrac{1}{2} \, ag \, . \, \tfrac{1}{4} \, a$$

$$s = \frac{a^2 g}{8 \, d} \quad \ldots \ldots \ldots \quad 1$$

$$d = \frac{a^2 g}{8 \, s} \quad \ldots \ldots \ldots \quad 2$$

The tension s exists at the apex (or vertex) of the parabola. At other points it is greater and reaches its maximum value at the supporting point A. The smaller d is in relation to a, however, the less will the tension at the support differ from the minimum stress s. In practice d is very small (the sag is only about $1\frac{1}{2}$ to 3 per cent. of the span), so that it may, with sufficient accuracy, be taken that the stress at the supporting points is equal to s.

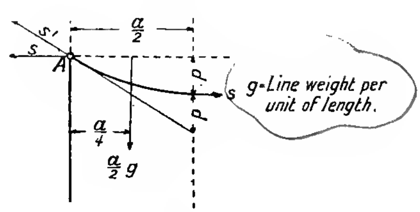


Fig. 3.

The equations 1 and 2 are independent of the temperature and hold for any condition of tension in the wire.

The flat parabola (Fig. 4) has a radius of curvature r at the apex equal to the parameter of the parabola, so that the length of arc corresponding to chord a and the angle ϕ is given by the expression :

$$\frac{L}{2} = r\phi \frac{\pi}{180} = r \sin^{-1} \frac{a}{2\,r}$$

$$\text{and } \sin^{-1} \frac{a}{2r} = \frac{a}{2r} + \frac{1}{2.3}\left(\frac{a}{2r}\right)^3 + \frac{1.3}{2.4.5}\left(\frac{a}{2r}\right)^5 + \ldots .$$

$$\therefore \frac{L}{2} = r \left[\frac{a}{2r} + \frac{1}{2.3}\left(\frac{a}{2r}\right)^3 + \frac{1.3}{2.4.5}\left(\frac{a}{2r}\right)^5 + \ldots . \right]$$

From Fig. 4: $\frac{a^2}{4} = 2\,rd$ from which the parameter of the parabola $r = \frac{a^2}{8d}$.

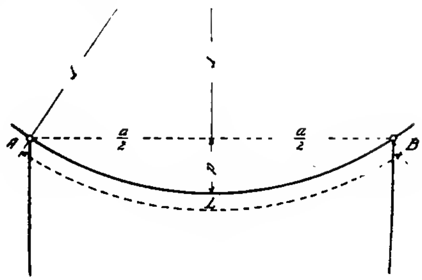


Fig. 4.

Inserting this in the above expression :

$$\frac{L}{2} = \frac{a^2}{8d}\left[\frac{a}{2} \cdot \frac{8d}{a^2} + \frac{1}{2.3}\left(\frac{a}{2} \cdot \frac{8d}{a^2}\right)^3 + \ldots . \right]$$

$$= \frac{a}{2}\left[1 + \frac{2}{3}\left(\frac{2d}{a}\right)^2 + \frac{2.3}{5}\left(\frac{2d}{a}\right)^4 + \ldots . \right]$$

and since $2d$ is very small compared with a, the higher powers may be neglected, giving :

$$L = a\left[1 + \frac{2}{3}\left(\frac{2\,d}{a}\right)^2\right] = a + \frac{8}{3} \cdot \frac{d^2}{a} \quad . \quad . \quad . \quad . \quad 3$$

(2) WITH SUPPORTING POINTS AT DIFFERENT LEVELS.

When the line is supported between two points at unequal heights the apex of the parabola no longer falls midway between them, *i.e.*, the parabola is not symmetrical. The symmetrical form is arrived at if the span is altered from AB either to $B'B$ (Fig. 5) or to AC (Fig. 6). In the former case an intermediate support B', and span a' are assumed, and in the latter case an external support C and a span a'' are assumed.

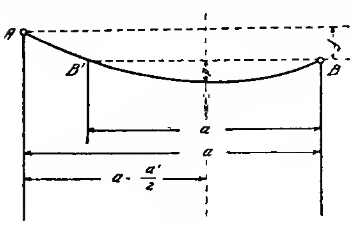


Fig. 5.

The imaginary spans can be determined from the results of the survey work on the route.

(*a*) Solution for Fig. 5 :—

The summation of the moments about A or B gives

$$s\,(d + f) = \left(a - \frac{a'}{2}\right) \times g \times \frac{a - \frac{a'}{2}}{2}$$

$$= \frac{g}{2}\left(a - \frac{a'}{2}\right)^2$$

$$sd = \frac{a'}{2}\,g\,\frac{a'}{4} = g\,\frac{a'^2}{8}$$

subtracting one equation from the other—

$$sf = \frac{g}{2}\left(a - \frac{a'}{2}\right)^2 - g\,\frac{a'^2}{8}$$

$$2\,sf = ga^2 - gaa' + g\,\frac{a'^2}{4} - g\,\frac{a'^2}{4}$$

or
$$a' = a - \frac{2\,sf}{ag} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 4$$

The sag d is found for the span a' in the same way as for supports of equal height.

(*b*) Solution for Fig. 6 :—

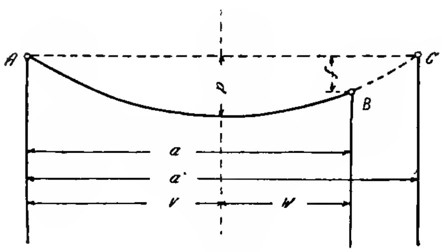


Fig. 6.

The summation of the moments about A and B gives

$$sd = \frac{a''}{2}\,g\,\frac{a''}{4}$$

$$s\,(d - f) = \left(a - \frac{a''}{2}\right) g\,\frac{a - \frac{a''}{2}}{2}.$$

Subtracting one of these equations from the other—

$$2\,sf = g\,\frac{a''^2}{4} - g\left(a - \frac{a''^2}{2}\right)^2$$

$$2\,sf = g\,\frac{a''^2}{4} - ga^2 - 2\,gaa''$$

$$a'' = a + \frac{2\,sf}{ag} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 5$$

The distance of the lowest point (apex of the parabola) from the supporting point A is :

$$V = \frac{a''}{2} = \tfrac{1}{2}\left(a + \frac{2\,sf}{ag}\right)$$

$$V = \frac{2\,sf + a^2g}{2\,ag} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 6$$

Its distance from the other supporting point B is :

$$W = a - \frac{a''}{2} = a - \tfrac{1}{2}\left(a + \frac{2\,sf}{ag}\right)$$

$$W = \frac{a^2g - 2\,sf}{2\,ag} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 7$$

If this equation gives a negative value the lowest point of the parabola lies outside the span, as shown in Fig. 7.

It is sometimes necessary, for instance in connection with undulating country,

to be able to determine the sag at any given distance V_p from the apex (Fig. 8). This can be done as follows :—

If r is the parameter of the parabola again :

$$V^2 = 2\,rd$$

$$(V_p)^2 = 2\,r\,.\,x_p$$

$$\text{For}\quad x_p = d - d_p$$

$$\frac{V^2}{d} = \frac{(V_p)^2}{d - d_p}$$

$$d_p = d\,\frac{V^2 - V_p{}^2}{V^2} \qquad . \quad . \quad . \quad . \quad . \quad 8$$

The position of the apex of the parabola with regard to the supports depends on the difference in level and on the distance between them. If the sag happens

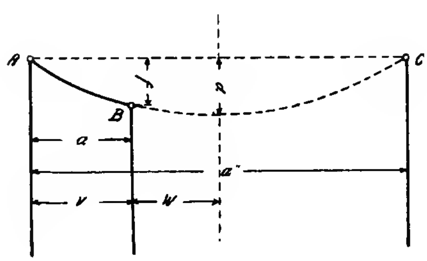


Fig. 7.

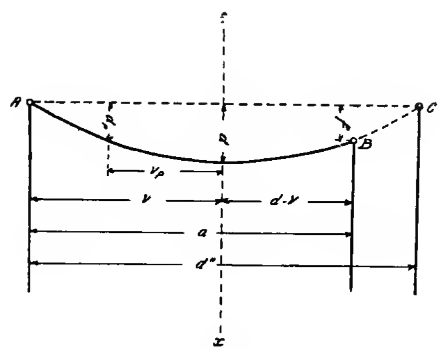


Fig. 8.

to be the same as the difference in level the apex will fall at the lower supporting point. With small spans and great differences of level the apex may even fall outside the span, as shown in Fig 7.

From the equation $d = \dfrac{a^2 g}{8\,s}$ (in which g stands for the weight of unit length of line of unit cross-section and s for the stress or tension per unit of cross-section) it is clear that the sag is independent of the cross-section of the wire and the following rule holds good : *The sag of a conductor for a given span with the same stress (lbs. per square inch) is the same for all areas of cross-section.*

This is of importance in practice, as it means that all the wires of the same material mounted on the same poles will have the same sag if tightened up to the same stress (lbs. per square inch).

NUMERICAL EXAMPLE 1.

Supports at the same Level.

Two masts for a high-tension transmission line are to be placed 400 feet apart. The cross-section of each of the copper wires is ·055 square inch. With

a specific gravity of 9 the weight of 1 foot of wire of 1 square inch section is 3·9 lbs. The tension in each wire at + 20° C. is to be 490 lbs. = 9,000 lbs. per square inch.

It is required to find the sag and the length of wire.

By equation 2:

$$d = \frac{a^2 g}{8\,s} = \frac{400^2 \times 3\ 9}{8 \times 9{,}000} = 8{\cdot}65 \text{ feet.}$$

$\dfrac{ft \times ft \times lb/(in \times in)/ft}{S \times lb/in^2}$

By equation 3:

$$L = a + \frac{8\,d^2}{3\,a} = 400 + \frac{8 \times (8{\cdot}65)^2}{3 \times 400} = 400{\cdot}5 \text{ feet.}$$

EXAMPLE 2.

Supports at different Levels.

Distance between masts, 650 feet. Difference in level at the two ends, 16 feet. Copper wires of ·055 square inch section. Weight of 1 foot of 1 square inch section = 3·9 lbs. Stress at + 10° C. = 8,800 lbs. per square inch (480 lbs. total tension per wire).

It is required to find the sag and the distances of the apex of the parabola from both supports.

By equation 2:

$$d = \frac{a^2 g}{8\,s}; \text{ and by equation 4:}$$

$$a' = a - \frac{2\,sf}{ag}$$

$$a' = 650 - \frac{2 \times 8{,}800 \times 16}{650 \times 3{\cdot}9} = 539 \text{ feet.}$$

$$d = \frac{(539)^2 \times 3{\cdot}9}{8 \times 8{,}800} = 16{\cdot}16 \text{ feet.}$$

If the calculation is worked out in reference to the higher of the two supports the results are as follows :—

By equation 5:

$$a'' = a + \frac{2\,sf}{ag}$$

$$= 650 + \frac{2 \times 8{,}800 \times 16}{650 \times 3{\cdot}9} = 761 \text{ feet.}$$

and $$d = \frac{a''^2 g}{8\,s} = \frac{(761)^2 \times 3{\cdot}9}{8 \times 8{,}800} = 32{\cdot}1 \text{ feet.}$$

By equation 6 :

$$V = \frac{2\,sf + a^2 g}{2\,ag}$$

$$= \frac{2 \times 8{,}800 \times 16 + (650)^2 \times 3{\cdot}9}{2 \times 650 \times 3{\cdot}9} = 380 \text{ feet.}$$

By equation 7:

$$W = \frac{a^2g - 2\,sf}{2\,ag}$$

$$= \frac{(650)^2 \times 3{\cdot}9 - 2 \times 8{,}800 \times 16}{2 \times 650 \times 3{\cdot}9} = 270 \text{ feet.}$$

EXAMPLE 3.

Supports at different Levels.

Distance between masts = 650 feet. Difference in level between the two supporting points = 130 feet. Transmission line consisting of three copper conductors each of ·055 square inch section. Weight of 1 foot length of copper 1 square inch in section = 3·9 lbs. Tension in each wire at 0° C. = 490 lbs. = 9,000 lbs. per square inch. It is required to find the sag and the position of the lowest point of the span (apex or vertex of the parabola).

By equation 5:

$$a'' = 650 + \frac{2 \times 9{,}000 \times 130}{650 \times 3{\cdot}9} = 1{,}575 \text{ feet.}$$

$$d = \frac{(1{,}575)^2 \times 3{\cdot}9}{8 \times 9{,}000} = 134 \text{ feet.}$$

By equation 6:

$$V = \frac{2\,sf + a^2g}{2\,ag}$$

$$V = \frac{2 \times 9{,}000 \times 130 + (650)^2 \times 3{\cdot}9}{2 \times 650 \times 3{\cdot}9} = 785 \text{ feet.}$$

By equation 7:

$$W = \frac{a^2g - 2\,sf}{2\,ag}$$

$$W = \frac{(650)^2 \times 3{\cdot}9 - 2 \times 9{,}000 \times 130}{2 \times 650 \times 3{\cdot}9} = -135 \text{ feet.}$$

i.e., the apex of the parabola lies outside the supporting points.

EXAMPLE 4.

Using the values given for example 2, find the sag at a point 163 feet from the high level supporting point.

It has been found that $d = 32{\cdot}16$ feet and $V = 380$ feet.

Putting these values into equation 8:

$$d_p = d\,\frac{V^2 - V_p^{\,2}}{V^2}, \text{ with } V_p = 380 - 163 = 217 \text{ feet,}$$

$$d_p = 32{\cdot}16\,\frac{(380)^2 - (217)^2}{(380)^2} = 21{\cdot}7 \text{ feet.}$$

The Effect of Temperature on the Tension and Sag of Conductors.

From equation 1 it is seen that the product of stress and sag is a constant for a given span and material of conductor; any diminution in sag results in an increase in stress, and *vice versâ*. The fact that all materials used as conductors increase in length when subjected to increased tension complicates the problem. The sag, in fact, does not increase so much as would be expected from equation 1, for as soon as the tension falls the wire contracts and shortens in length and so diminishes the sag.

When the line is erected between its supports it is given a certain tension and sag. These will not be permanently retained however, but will vary with any additional loads on the wire and with temperature changes. The former are produced by wind force or by snow or ice accumulations on the wire, which act as an addition to the tension due to the wire's own weight, and so lengthen out the wire and increase the sag. The ordinary atmospheric variations of temperature lengthen or shorten the wire more or less according to the value of the thermal expansion coefficient of the material.

In the following calculations:

s_0 = maximum allowable stress in lbs. per square inch;
s_t = stress at temperature $t°$ C.;
L_0 = length of the conductor when subjected to the maximum stress;
L_t = length of conductor at temperature $t°$ C.;
g = weight of 1 foot of the conductor material 1 square inch in section, in lbs.;
g_z = additional load in lbs. per 1 foot length of conductor 1 square inch in section;
a = length of span in feet;
d = sag in feet;
t = temperature in ° C. for which s_t and d are to be determined;
α = thermal expansion coefficient for the material;
β = elastic extension coefficient $(= \frac{1}{E})$.

In accordance with equation 3, the length of a conductor hanging in the shape of a flat parabola is:

$$\boxed{L = a + \frac{8}{3}\frac{d^2}{a}.}$$

If the temperature is raised the wire expands in length by an amount equal to α feet for each foot length of wire and for each 1° C. rise. Each piece of wire which originally measured 1 foot will lengthen by an amount equal to αt when the temperature rises by $t°$ C., so that the total additional length will be $L \alpha t$ and the new total length will be $L' = L + L \alpha t$.

The elasticity of the material counteracts this extension, for under the influence of the increased length the tension falls and the material draws itself together.

The ratio of the increase in length to the original length is called the strain, and this is proportional to the stress up to the elastic limit of stress for the material.

The ratio $\frac{\text{strain}}{\text{stress}} = \beta$ is called the extension coefficient, and its reciprocal $\frac{1}{\beta} = E$ is called Young's modulus of elasticity, *i.e.*, that imaginary load or stress at which a wire, say, 1 foot long would become extended by an equal length of 1 foot, assuming that the elastic limit were not previously reached, so that the initial rate of extension continued to hold good.

If the stress on a wire of length L is reduced by s lbs. per square inch the wire will become shortened by an amount equal to $L s \beta$.

Starting with the lowest temperature t_o, at which the length of line is L_o, and calling the length corresponding to a temperature $t°$ L', this new length would be :

$$L' = L_o + L_o\alpha(t - t_o) = L_o[1 + \alpha(t - t_o)],$$

$(t - t_o)$ being the temperature difference considered.

Owing to the elastic contraction, however, the length of wire at temperature t is not L' but only L_t, where

$$L_t = L_o[1 + \alpha(t - t_o)] + L_o\beta(s_t - s_o),$$

Here s_o is the maximum stress occurring at the lowest temperature t_o and s_t is the stress to be expected at the higher temperature t.

Further $$L_t = a + \frac{8}{3}\frac{d_t^2}{a}, \; L_o = a + \frac{8}{3}\frac{d_o^2}{a},$$

or $$a + \frac{8}{3}\frac{d_t^2}{a} = a + \frac{8}{3}\frac{d_o^2}{a} + L_o\alpha(t - t_o) + L_o\beta(s_t - s_o).$$

In the two last terms it is quite permissible to replace the length of wire L_o by the length of span a, so that

$$a + \frac{8}{3}\frac{d_t^2}{a} = a + \frac{8}{3}\frac{d_o^2}{a} + a\,\alpha\,(t - t_o) + a\beta(s_t - s_o).$$

Substituting the values for d_t and d_o in this $\left(\text{viz., } d_t = \frac{a^2 g}{8 s_t} \text{ and } d_o = \frac{a^2 g}{8 s_o}\right)$, the result is :

$$\frac{1}{3}\frac{a^2g^2}{8\,s_t^2} = \frac{1}{3}\frac{a^2g^2}{8\,s_o^2} + \alpha(t - t_o) + \beta(s_t - s_o),$$

and from this :

$$s_t - \frac{a^2g^2}{24\,s_t^2\beta} = s_o - \frac{a^2g^2}{24\,s_o^2\beta} - \frac{\alpha}{\beta}(t - t_o) \quad . \quad . \quad . \quad 9$$

The minimum temperature t_o is, in Mid Europe, commonly taken as $-20°$ C. The rules of the Verband Deutscher Elektrotechniker specify that the stress conditions are to be calculated both for a minimum temperature of $-20°$ C. without additional load and also for a temperature of $-5°$ C. with an assumed additional ice and snow load amounting to ·015 kg. per metre length and per

square millimetre of cross-section (6·6 lbs. per foot length and per square inch of cross-section.)

For these two cases the equation then is :

$$s_t - \frac{a^2 g^2}{24\, s_t^2 \beta} = s_o - \frac{a^2 g^2}{24\, s_o^2 \beta} - \frac{\alpha}{\beta}(t + 20) \quad . \quad . \quad . \quad 10$$

and

$$s_t - \frac{a^2 g^2}{24\, s_t^2 \beta} = s_o - \frac{a^2 g_z^2}{24\, s_o^2 \beta} - \frac{\alpha}{\beta}(t + 5) \quad . \quad . \quad . \quad 11$$

If the numerical values given by these two equations are worked out for various spans it will be found that up to a certain length of span the — 20° C. rule gives the greater stresses, whilst beyond this span the — 5° C. with snow and ice load works out as the higher.

Schauer* has worked out the expression for this critical span and finds that its value is given by

$$a = 6\, s \sqrt{\frac{10\, \alpha}{g_z^2 - g^2}} \quad . \quad . \quad . \quad . \quad 12$$

where a = span in feet ;
s = allowable stress in lbs. per square inch ;
g = weight of line material in lbs. per foot length and 1 square inch section ;
g_z = weight of line loaded with snow and ice per foot length and 1 square inch cross-section ;
α = thermal coefficient of expansion.

This formula gives the following values for the critical lengths of span :—

	lbs. per sq. inch.		feet.
Hard-drawn copper with a maximum working stress of	21,500	..	166
Medium copper wire ,, ,,	15,800	..	124
Soft copper wire ,, ,,	7,200	..	56
Bronze wire ,, ,,	40,000	..	326
"Monnot metal" (or copper-clad steel) wire with a maximum working stress of	57,000	..	390
Aluminium wire with a maximum working stress of .	10,000	..	117
Steel wire ,, ,,	72,000	..	490
Iron wire ,, ,,	34,000	..	235

Example 5.

A H.T. line of hard drawn copper is erected on masts 390 feet apart. What sag must it be given at + 10° C. ?

For hard drawn copper with a maximum working stress of 21,500 lbs. per square inch the above table shows that the critical span is 166 feet, consequently the maximum tension when the span is 390 feet will occur at — 5° C. with addi-

* Elektrische Kraftbetriebe und Bahnen, 1910.

tional load (and not at — 20° C. without additional load of ice and snow). Using equation 11, therefore, and the values in Table 1 :

$$s_t - \frac{(3{\cdot}9)^2 \times (390)^2}{24 \times {\cdot}53 \times 10^{-7} \times s_t^2} = 21{,}500 - \frac{(6{\cdot}6 + 3{\cdot}9)^2 \times (390)^2}{24 \times {\cdot}53 \times 10^{-7} \times (21{,}500)^2} - \frac{1{\cdot}68 \times 10^{-5}}{{\cdot}53 \times 10^{-7}}(10 + 5)$$

from which $$s_t^3 + 11{,}800\, s_t^2 - 1{\cdot}82 \times 10^{12} = 0.$$

By substituting for s_t the expression $x - \dfrac{11{,}800}{3} = x - 3{,}933$, the above is reduced to $x^3 - 46{\cdot}2 \times 10^6\, x - 1{\cdot}7 \times 10^{12} = 0$. Solving this by means of Cardan's method, $x = 13{,}200$, or

$$s_t = x - 3{,}933 = 13{,}200 - 3{,}933 = 9{,}267 \text{ lbs. per square inch.}$$

The sag is then $$d = \frac{a^2 g}{8\, s_t} = \frac{(390)^2 \times 3{\cdot}9}{8 \times 9{,}267} = 8 \text{ feet.}$$

EXAMPLE 6.

A line passing over undulating country has to cross a cutting having a span of 1,250 feet and a depth of 66 feet as shown in Fig. 9. It is required to know whether this span can be bridged with hard drawn copper wire weighing 3·9 lbs. per foot of 1 square inch section, without exceeding a stress of 21,500 lbs. per square inch and without letting the line approach the ground by less than 20 feet. The height of the masts up to the lowest cross-arm is 30 feet.

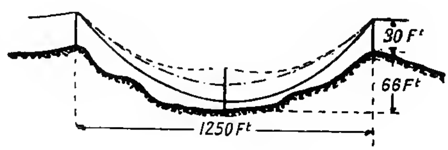


Fig. 9.

In this case the points to be considered are the sag at the highest temperature (+ 40° C.) and the maximum tension, which will occur at the — 5° C. temperature with the additional ice and snow load.

By equation 11 :

$$s_t - \frac{a^2 g^2}{24\, s_t^2 \beta} = s_o - \frac{a^2 g_z^2}{24\, s_o^2 \beta} - \frac{\alpha}{\beta}(t + 5)$$

or $$s_t - \frac{1{,}250^2 \times 3{\cdot}9^2}{24 \times s_t^2 \times {\cdot}53 \times 10^{-7}} = 21{,}500 - \frac{1{,}250^2 \times 10{\cdot}5^2}{24 \times 21{,}500^2 \times {\cdot}53 \times 10^{-7}} - \frac{1{\cdot}68 \times 10^{-5}}{{\cdot}53 \times 10^{-7}}(40 + 5),$$

from which $$s_t = 7{,}900 \text{ lbs. per square inch.}$$

The sag then is :

$$d = \frac{a^2 g}{8\, s_t} = \frac{1{,}250^2 \times 3{\cdot}9}{8 \times 7{,}900} = 95 \text{ feet.}$$

Also the sag at $-$ 5° C. with additional load is :

$$d = \frac{a^2 g_z}{8\,s_o} = \frac{1{,}250^2 \times 10{\cdot}5}{8 \times 21{,}500} = 94{\cdot}5 \text{ feet.}$$

The maximum sag, therefore, occurs at + 40° C. Since the bottom of the cutting is only 66 feet deep it will not be possible to effect this crossing in the way suggested, using masts 30 feet high. Three ways are available for getting over the difficulty :—

(1) The height of mast may be increased from 30 to 50 feet. This involves heavy and expensive masts with correspondingly heavy foundations.

(2) The line may be supported on a central mast at the bottom of the cutting at a sufficient height to give the required minimum clearance at all points. In this case the central mast may be taken as 40 feet high, so as to allow for the fact that the line will hang in the form of two parabolas, each having a certain amount of sag. The case is, therefore, that of a line having a difference of level between the two supports of 56 feet and a span of 625 feet.

By equation 5 :

$$a'' = a + \frac{2\,sf}{ag_z} = 625 + \frac{2 \times 21{,}500 \times 56}{625 \times 10{\cdot}5} = 990 \text{ feet.}$$

Knowing this imaginary span a'', the tension in the wire at 40° C. can be found by equation 11 :

$$s_t - \frac{990^2 \times 3{\cdot}9^2}{24 \times s_t^2 \times {\cdot}53 \times 10^{-7}} = 21{,}500 - \frac{990^2 \times 10{\cdot}5^2}{24 \times 21{,}500^2 \times {\cdot}53 \times 10^{-7}}$$
$$- \frac{1{\cdot}68 \times 10^{-5}}{{\cdot}53 \times 10^{-7}}\,(40 + 5),$$

from which $s_t = 7{,}900$ lbs. per square inch.

The sag at 40° C. $= d = \dfrac{990^2 \times 3{\cdot}9}{8 \times 7{,}900} = 60$ feet.

The sag at $-$ 5° C. with additional load $= d = \dfrac{990^2 \times 10{\cdot}5}{8 \times 21{,}500} = 59{\cdot}7$ feet.

Since the difference in level between the supporting points is 56 feet, the lowest point of the line will lie about 4 feet lower than the bottom support, viz., at a height of about 36 feet above the ground. This lowest point is found by equation 6 to be :

$$V = \frac{2 \times 7{,}900 \times 56 + 625^2 \times 3{\cdot}9}{2 \times 625 \times 3{\cdot}9} = 500 \text{ feet}$$

away from the higher supporting point.

Since the bottom of the cutting is not quite horizontal, but rises somewhat at the sides, the extra clearance available (36 feet in place of 20 feet) will be an advantage.

(3) The third possible solution lies in choosing a conductor material which can safely be tightened so as to hang with less sag. If bronze is selected

with a safe working stress of 36,000 lbs. per square inch the stress at $+ 40°$ C. is obtained by equation 11 :

$$s_t - \frac{(1{,}250)^2 \times (3 \cdot 8)^2}{24 \times s_t^2 \times \cdot 59 \times 10^{-7}} = 36{,}000 - \frac{(1{,}250)^2 \times (10 \cdot 4)^2}{24 \times (36{,}000)^2 \times \cdot 59 \times 10^{-7}} - \frac{1 \cdot 8 \times 10^{-5}}{\cdot 59 \times 10^{-7}}(40 + 5),$$

from which $s_t = 15{,}400$ lbs. per square inch,

and the sag is $$d = \frac{(1{,}250)^2 \times 3 \cdot 8}{8 \times 15{,}400} = 48 \cdot 5 \text{ feet.}$$

At $-5°$ C. with additional ice and snow load the sag is :

$$d = \frac{(1{,}250)^2 \times 10 \cdot 4}{8 \times 36{,}000} = 56 \text{ feet.}$$

The lowest point of the line will therefore be $66 + 30 - 56 = 40$ feet above the floor of the cutting. The sag could, therefore, be considerably increased even, and this would reduce the tension and enable less powerful masts to be used. The permissible maximum sag is $96 - 20 = 76$ feet. This maximum sag will occur at $-5°$ C. with additional load and will correspond to a stress

$$s_o = \frac{(1{,}250)^2 \times 10 \cdot 4}{8 \times 76} = 26{,}500 \text{ lbs. per square inch.}$$

The above example shows that the maximum sag does not always occur under the same circumstances ; it may, in fact, either occur at the highest temperature or at the low temperature when the additional load due to ice and snow is present. The two sags will be alike when the extension due to the additional load in the one case happens to be equal to the elongation due to the temperature rise in the other case. The temperature for which this holds good can be found as follows :—

The sag at $-5°$ C. with additional load is :

$$d = \frac{a^2 g_z}{8\, s_o}.$$

At the temperature $t°$ C. the sag is :

$$d = \frac{a^2 g}{8\, s_t}.$$

Equating these two values :

$$\frac{a^2 g_z}{8\, s_o} = \frac{a^2 g}{8\, s_t}, \text{ or } \frac{g_z}{s_o} = \frac{g}{s_t}, \text{ or } s_t = s_o \frac{g}{g_z}.$$

Inserting this value in equation 11 gives :

$$s_o \frac{g}{g_z} - \frac{a^2 g^2 g_z^2}{24\, s_o^2 g^2 \beta} = s_o - \frac{a^2 g_z^2}{24\, s_o^2 \beta} - \frac{\alpha}{\beta}(t + 5),$$

or $$s_o \frac{g}{g_z} = s_o - \frac{\alpha}{\beta}(t + 5),$$

and $$t = s_o \left(1 - \frac{g}{g_z}\right) \frac{\beta}{\alpha} - 5 \quad . \quad . \quad . \quad . \quad . \quad 13$$

i.e., the temperature at which the sag due to the line's own weight is equal to the sag at — 5° C. due to the line's weight together with additional load is independent of the length of span.

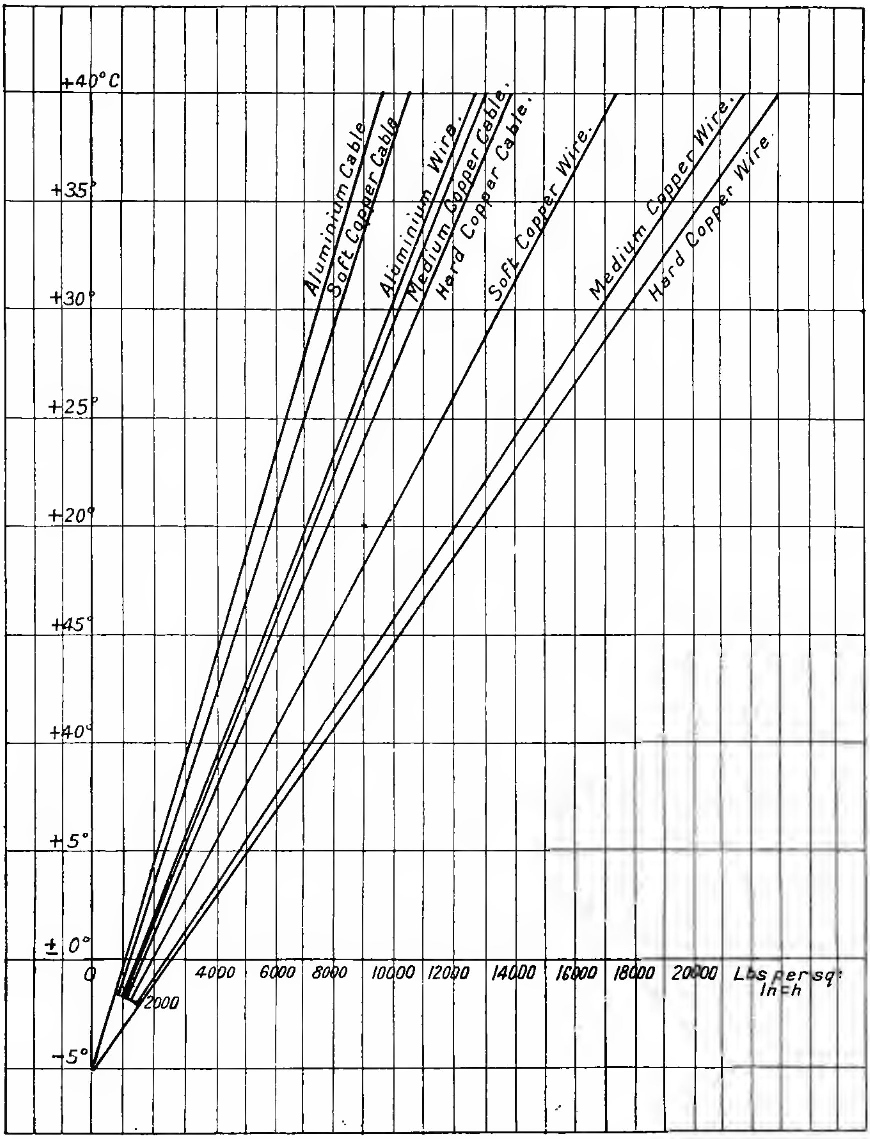


Fig. 10.

The stress to which the line must be subjected to make the sags alike is

$$s_o = \frac{\alpha}{\beta}(t + 5) \times \frac{g_z}{g_z - g} \qquad . \quad . \quad . \quad . \quad . \quad 14$$

or, with $t = 40°$ C., $$s_o = 45 \frac{\alpha}{\beta} \left(\frac{g_z}{g_z - g}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 15$$

From this equation the following values are obtained :—

Metal.	Stress in lbs. per sq. inch.	
	Single Wire.	Stranded Cable.
Hard drawn copper	22,700	13,800
Medium copper	21,500	13,000
Soft copper	17,200	10,500
Aluminium	12,700	9,600
Bronze with 71,000 lbs. per sq. inch breaking stress	12,700	9,600
,, ,, 100,000 ,, ,, ,,	22,000	13,400
Copper-clad steel ,, 83,000 ,, ,, ,,	23,200	13,800
,, ,, ,, 128,000 ,, ,, ,,	25,000	15,200
Steel ,, 100,000 ,, ,, ,,	22,700	13,500
,, ,, 130,000 ,, ,, ,,	24,500	14,800
,, ,, 185,000 ,, ,, ,,	25,200	15,300

If these values are selected as the maximum working stresses the sag at $-5°$ C. with additional load will be the same as at $+40°$ C. With higher stresses the maximum sag will occur at $-5°$ with additional load, whilst with lower stresses the maximum sag will occur at $+40°$ C.

The stresses which must be selected in order that the sag at $-5°$ C. with additional load shall be the same as at any other given temperature between $-5°$ C. and $+40°$ C. are shown in Fig. 10 for copper and aluminium wires and cables.

EXAMPLE 7.

A H.T. line consisting of a stranded copper rope or cable of ·078 square inch cross-section crosses a road at right angles. The maximum stress that is ever to occur is not to exceed 5,700 lbs. per square inch. At what height above the roadway must the lowest cross-arm be placed in order that the line shall never approach nearer than 23 feet to the road ? The general arrangement is shown in Fig. 11.

Using equation 12, the critical length of span works out as :

$$a = 6\,s\sqrt{\frac{10\,\alpha}{g_z^2 - g^2}} = 6 \times 5{,}700\sqrt{\frac{10 \times 1{\cdot}68 \times 10^{-5}}{10{\cdot}5^2 - 3{\cdot}9^2}} = 46 \text{ feet},$$

therefore the maximum stress will occur at $-5°$ C. with additional snow and ice load, and by equation 2 :

$$d = \frac{a^2 g}{8\,s} = \frac{130^2 \times (3{\cdot}9 + 6{\cdot}6)}{8 \times 5{,}700} = 3{\cdot}9 \text{ feet},$$

Since the selected stress is less than 13,800 lbs. per square inch the maximum sag will occur at + 40° C. and the stress s_t at this temperature is found by equation 11 :

$$s_t - \frac{130^2 \times 3{\cdot}9^2}{24\, s_t^2 \times {\cdot}89 \times 10^{-7}} = 5{,}700 - \frac{130^2 \times 10{\cdot}5^2}{24 \times 5{,}700 \times {\cdot}89 \times 10^{-7}} - \frac{1{\cdot}68 \times 10^{-5}}{{\cdot}89 \times 10^{-7}} (40 + 5)$$

from which $s_t = 1{,}680$ lbs. per square inch.

By equation 2 the sag at this temperature of 40° C. is, therefore,

$$d_{40} = \frac{a^2 g}{8\, s_t} = \frac{130^2 \times 3{\cdot}9}{8 \times 1{,}680} = 5 \text{ feet.}$$

Should the line accidentally break on both sides beyond the roadway the suspension insulators would swing inwards and so shorten the effective

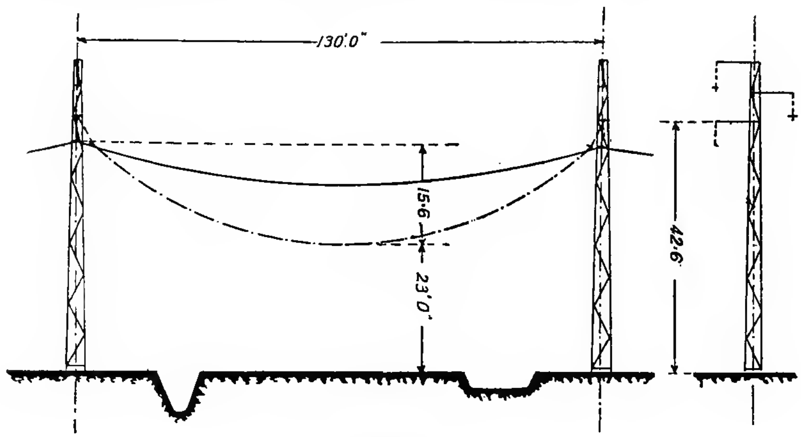


Fig. 11.

span and increase the sag. Assuming that the insulators swing out of the vertical by an angle of, say, 35°, and that the length of the suspension is 4 feet, the reduction in span would amount to $2 \times 2{\cdot}35 = 4{\cdot}7$ feet (since an angle of 35° subtends a chord of 2·35 at a radius of 4 feet).

The maximum length of wire in the span occurs at + 40° C. and is :

$$L_{40} = a + \frac{8\,(d_{40})^2}{3 \times a} = 130 + \frac{8 \times 5^2}{3 \times 130} = 130{\cdot}5 \text{ feet.}$$

When the outer wires break and the temperature is + 40° C., this length of wire will exist in a span of $130 - 4{\cdot}7 = 125{\cdot}3$ feet.

Using the equation

$$L = a + \frac{8\, d^2}{3\, a},$$

the value of the new sag is found to be:

$$d = \sqrt{\frac{3}{8}(L - a)\, a} = \sqrt{\frac{3}{8}(130{\cdot}5 - 125{\cdot}3)\, 125{\cdot}3} = 15{\cdot}6 \text{ feet.}$$

The height to the lowest cross-arm will therefore be made up as follows :—

	Feet.
Minimum height above roadway	23
Sag with outer wires broken	15·6
Length of insulator chain	4
Height	42·6

SAG AND STRESS IN INSULATED CONDUCTORS.

The formulæ developed above are also directly applicable to the case of insulated conductors. The weight of line is made up of the weight of the conductor and the uniformly distributed weight of insulation material. The thickness of the insulating covering is approximately the same for all the ordinary wire sections (·01 to ·2 square inch). Since the specific gravity of the insulation is decidedly less than that of the conductor, it follows that the total weight per unit of length and per unit of cross-sectional area diminishes with increasing diameters. It is therefore necessary to use different stresses with insulated wires of different cross-sections if all are to hang with the same amount of sag.

The additional load due to ice and snow depends on the gross cross-section q_i of the insulated wire instead of on the net cross-section q of the wire itself. The additional load per foot run and per square inch section of conductor is, therefore, $6{\cdot}6 \times \frac{q_i}{q}$ in place of 6·6 lbs.

If g_i is the gross weight of the insulated conductor in lbs. per foot run, equation 2 for sag becomes :

$$d = \frac{a^2}{q} \times \frac{g_i + 6{\cdot}6\, q_i}{8\, s} \quad . \quad . \quad . \quad . \quad . \quad . \quad 16$$

and

$$s = \frac{a^2}{q} \times \frac{g_i + 6{\cdot}6\, q_i}{8\, d} \quad . \quad . \quad . \quad . \quad . \quad . \quad 17$$

The critical length of span, allowing for the variable weight per unit of gross cross-section, is different for each section. For the limiting cross-sections covered by Table 7 (·0093 and ·186 square inch) and for a maximum stress of 14,300 lbs. per square inch of conductor, equation 12 becomes :—

$$a = 6 \times 14{,}300 \sqrt{\frac{10 \times 1{\cdot}68 \times 10^{-5}}{\frac{{\cdot}35^2 - {\cdot}054^2}{({\cdot}0093)^2}}} = 29{\cdot}8 \text{ feet.}$$

for the ·0093 square inch wire,

and

$$a = 6 \times 14{,}300 \sqrt{\frac{10 \times 1{\cdot}68 \times 10^{-5}}{\frac{3{\cdot}42^2 - {\cdot}82^2}{({\cdot}186)^2}}} = 63 \text{ feet.}$$

for the ·186 square inch wire.

As these spans are very short, the maximum stress will usually occur at — 5° C. with additional load rather than at — 20° C. without additional load.

In order to determine at what temperature the sag of an insulated conductor without additional load will be the same as at — 5° C. with additional load, equation 13 can be used.

For the ·0093 square inch section wire :

$$t = 14{,}300\left(1 - \frac{\cdot 054}{\cdot 35}\right) \times \frac{\cdot 56 \times 10^{-7}}{1\cdot 68 \times 10^{-5}} - 5 = 35\cdot 1^\circ \text{ C.}$$

and for the ·186 square inch section :

$$t = 14{,}300\left(1 - \frac{\cdot 82}{3\cdot 42}\right) \times \frac{\cdot 93 \times 10^{-7}}{1\cdot 68 \times 10^{-5}} - 5 = 55\cdot 2^\circ \text{ C.}$$

The maximum sag will, therefore, usually occur at — 5° C. with additional load for ordinary copper wires of medium hardness worked with a maximum stress of 14,000 to 17,000 lbs. per square inch.

EXAMPLE 8.

Owing to the neighbourhood of postal wires a certain overhead local distribution scheme is to be carried out with insulated wires. The sections of the wires are ·0093 square inch and ·054 square inch and the distance between the poles is 130 feet. What amount of sag must be given to the smaller wires in order to keep the maximum stress to 14,300 lbs. per square inch ?

What stress will the larger wire be subjected to if it is to have the same sag as the smaller wire ?

From Table 7 for insulated copper conductors it is seen that

	Lbs. per foot run.
For a ·0093 square inch wire	g_i = ·054
,, ·054 ,, ,, ...	g_i = ·255
	Inch.
For a ·0093 square inch wire, the outside diameter . .	= ·24
,, ·054 ,, ,, ,, ,, . .	= ·46
	Square inch.
For a ·0093 square inch wire, the gross cross-section . .	q_i = ·045
,, ·054 ,, ,, ,, ,, . .	q_i = ·167

The sag of the ·0093 square inch wire at — 5° C. with additional load is, by equation 16 :

$$d = \frac{130^2}{\cdot 0093} \times \frac{\cdot 054 + 6\cdot 6 \times \cdot 045}{8 \times 14{,}300} = 5\cdot 56 \text{ feet.}$$

For the same sag the maximum stress in the ·054 square inch wire will be

$$s = \frac{130^2}{\cdot 054} \times \frac{\cdot 255 + 6\cdot 6 \times \cdot 167}{8 \times 5\cdot 56} = 9{,}600 \text{ lbs. per square inch.}$$

SAG AND STRESS IN SAFETY NETWORK CONDUCTORS.

In the special network conductors sometimes used at important crossings, the weight of the longitudinal wires is increased by that of the cross wires, which may be considered as uniformly distributed over the length.

The sag and stress of the longitudinal wires can, therefore, be determined by equations 16 and 17 if for the weight g_i the total weight of longitudinal and cross wires is used, and if the total additional load of ice and snow for the combined cross-sections q_i of the longitudinal and cross wires is worked out and reduced to the cross-section actually subjected to stress.

The factor of safety should be made at least 4, because the additional load specification is rather low for small sections of wire and because the cross points in the network conductor encourage the collection of snow.

Sag and Stress of Steel Wire Ropes Supporting Cables.

Telephone wires run underneath H.T. transmission lines are sometimes made up in the form of a two-core lead-covered cable, in order to ensure satisfactory speaking even in case of an earth fault in the H.T. lines. Such a cable is supported by means of a steel wire rope. The loading of this rope can be considered as uniformly distributed, and the effective weight on the rope can be taken as equal to the weight of the steel itself together with that of the conductor cable and the supporting links. The additional load due to ice and snow must be estimated from the total cross-section of the steel rope and the cable.

Sometimes the space between the steel rope and the cable may become completely filled with snow and ice, and in that case the usual allowance is far exceeded, so that an ample factor of safety should be employed in these constructions.

Example 9.

Underneath a H.T. copper line of ·055 square inch and having a span of 490 feet and a maximum sag (at — 5° C. and with additional load due to ice and snow) of 14·2 feet, a steel wire rope of ·062 square inch section, 185,000 lbs. per square inch breaking stress, and a weight of ·22 lb. per foot run is suspended. To this rope a telephone cable is attached having an outside diameter of ·59 inch and a weight of ·56 lb. per foot run.

With what sag should the steel rope be erected if the maximum working stress in it is not to exceed 50,000 lbs. per square inch ?

By equation 16 :

$$d = \frac{490^2}{\cdot 062} \times \frac{(\cdot 22 + \cdot 56) + 6\cdot 6\left(\cdot 062 + \cdot 59^2 \times \frac{\pi}{4}\right)}{8 \times 50{,}000} = 28\cdot 8 \text{ feet.}$$

Since the sag of the steel rope is more than double that of the H.T. copper line, it will be advisable to increase the sag of the latter by reducing its stress to between 14,000 and 17,000 lbs. per square inch so as to relieve the strain towers and corner poles somewhat.

The temperature at which the sag of the steel rope will be the same as at — 5° C. with additional load can be found by equation 13 :

$$t = 50{,}000\left(1 - \frac{(\cdot 22 + \cdot 56)}{\cdot 22 + \cdot 56 + 6\cdot 6\left(\cdot 062 + \cdot 59^2 \times \frac{\pi}{4}\right)}\right) \times \left(\frac{\cdot 55 \times 10^{-7}}{1\cdot 2 \times 10^{-5}}\right) - 5^\circ$$

$$= 163^\circ \text{ C.}$$

In Tables 9 to 12 particulars as to sag and stress in bare copper cables with various spans are collected. The weight of the cable has been taken as 4·05 lbs. per foot run of 1 square inch cross-section, which corresponds approximately

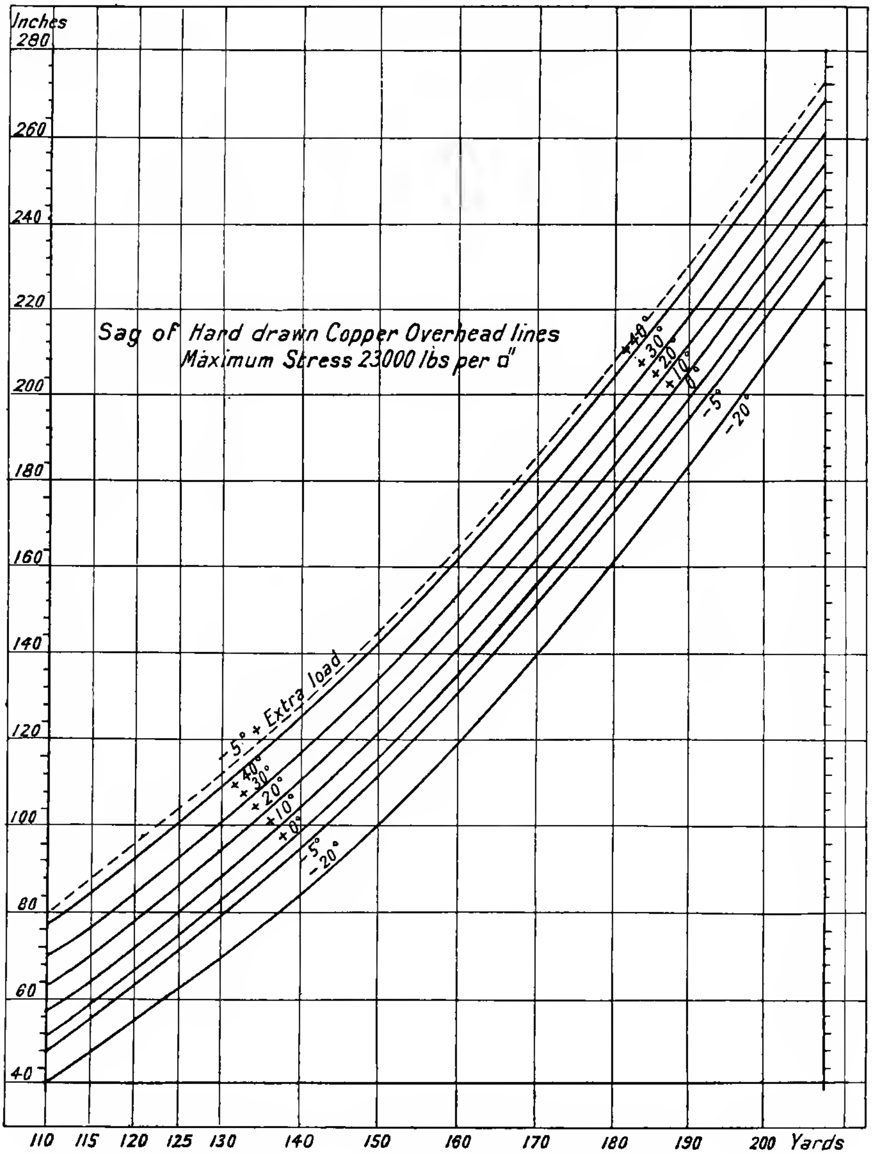


Fig. 12.

to a lay of seven times the diameter. For longer lays than this (up to fifteen times the diameter) the weight can be taken as 4 to 4·03 lbs. per foot run and 1 square inch section.

In dealing with cables it must be remembered that their modulus of elasticity is considerably less than for solid wires (see Tables 1 to 5).

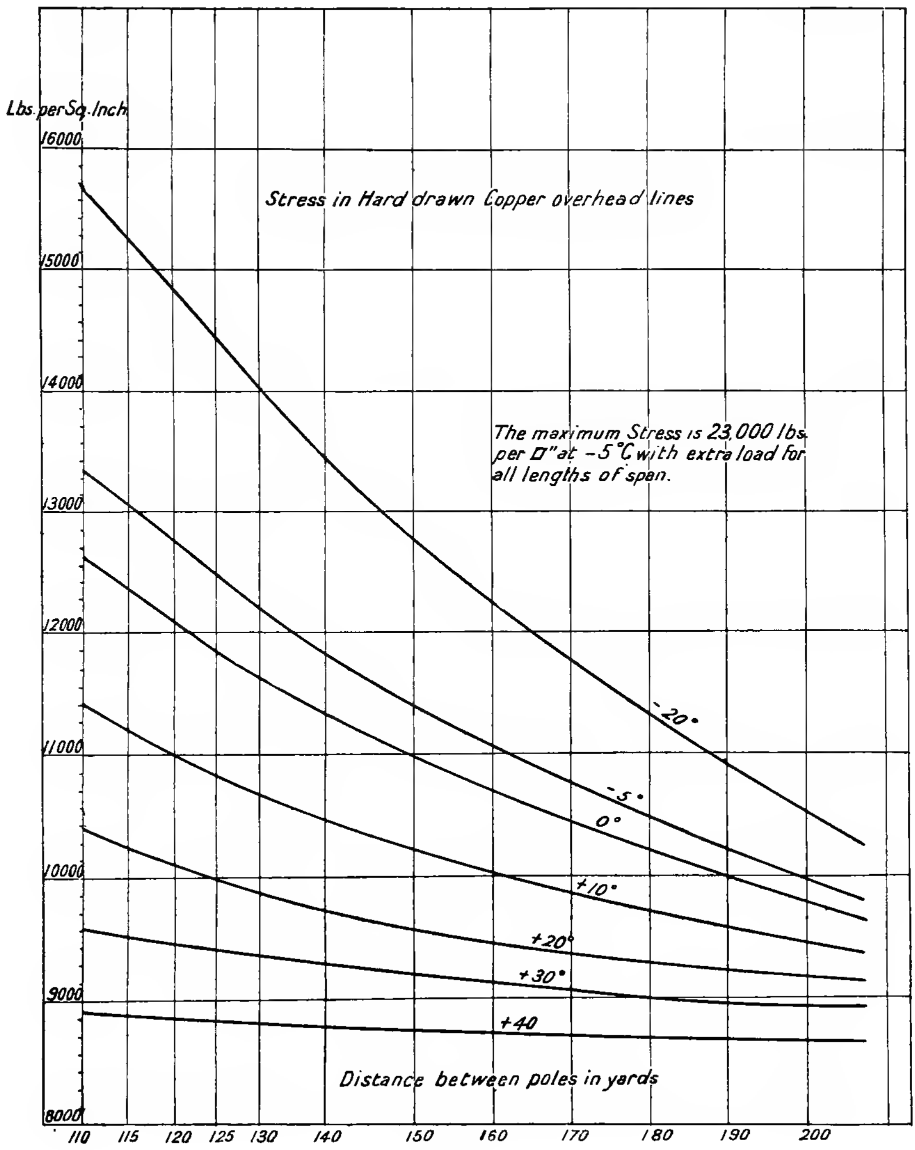


Fig. 13.

The sag and stress for solid copper wires with a weight of 3·9 to 3·97 lbs. per foot run of 1 square inch section can be read off the curves in Figs. 12 and 13.

TABLE 9.—*Sag and Stress in Bare Hard Drawn Copper Cables.*

Maximum stress, 5,700 lbs. per square inch; sag (D), in inches; stress (Z), in lbs. per square inch.

Span in Metres	10		14		18		22		26		30		34		38	
Span in Feet.	32·5		45·5		58·5		72		85		98		111		124	
Temperature °C.	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z
— 20	1·15	5,700	2·2	5,700	4·8	4,330	9·1	3,500	14·5	3,030	21	2,760	28·5	2,630	37·1	2,520
— 5 (with additional load of ice and snow)	3·55	4,950	5·95	5,700	9·7	5,700	14·4	5,700	20	5,700	26·8	5,700	34·2	5,700	43	5,700
0	1·62	3,700	4·1	4,000	7·7	2,720	12·3	2,550	17·9	2,450	24·8	2,360	31·8	2,350	40·4	2,350
+ 5	2·16	3,000	4·75	2,670	8·4	2,500	13·1	2,400	18·8	2,340	25·6	2,300	32·7	2,300	41·5	2,280
+ 10	2·6	2,500	5·4	2,370	9·2	2,300	13·9	2,270	19·5	2,250	26·2	2,230	33·5	2,230	42·7	2,220
+ 15	3·15	2,060	6·1	2,100	9·8	2,150	14·6	2,150	20·3	2,160	26·8	2,180	34·6	2,170	43·5	2,160
+ 20	3·64	1,800	6·6	1,930	10·5	2,000	15·3	2,060	21	2,100	27·5	2,120	35·5	2,100	44·8	2,100
+ 25	4·15	1,570	7·3	1,750	11	1,900	15·9	1,990	21·7	2,030	28·3	2,060	35·7	2,080	45·5	2,080
+ 30	4·55	1,420	7·8	1,650	11·8	1,800	16·6	1,890	22·5	1,960	29·1	2,000	36·4	2,060	46·2	2,050
+ 35	5·05	1,290	8·3	1,530	12·4	1,700	17·3	1,820	23	1,900	29·7	1,960	37	2,020	47	2,000
+ 40	5·45	1,190	8·9	1,440	13	1,630	17·9	1,760	23·8	1,850	30·5	1,920	37·5	2,000	47·9	1,970

TABLE 10.—*Sag and Stress in Bare Hard Drawn Copper Cables.*

Maximum stress, 11,400 lbs. per square inch (at — 5° C. with additional load); sag (D), in inches; stress (Z), in lbs. per square inch.

Span in Metres.	30		40		50		60		80		100		120		140	
Span in Feet.	98		130		163		196		260		326		390		455	
Temperature ° C.	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z
— 20	5·3	11,000	9·5	9,200	20·2	7,400	37	6,300	78	5,300	132	4,950	196	4,750	273	4,650
— 5 (with additional load)	13·4	11,400	23·6	11,400	37	11,400	54	11,400	95	11,400	149	11,400	215	11,400	291	11,400
0	7·5	7,900	15	6,950	28	5,800	44	5,350	85	4,900	139	4,700	204	4,600	280	4,520
+ 5	8·3	7,200	16·5	6,300	29·6	5,500	45·5	5,150	87	4,800	140	4,620	205	4,550	282	4,500
+ 10	9·1	6,400	17·7	5,900	31·2	5,250	47	5,000	88·3	4,700	141·2	4,600	206	4,500	283	4,490
+ 15	9·8	5,900	19	5,500	32·3	5,000	48·5	4,800	90	4,600	143	4,550	207	4,480	285	4,460
+ 20	10·6	5,600	20	5,100	33·5	4,800	50	4,650	91·5	4,530	145	4,500	209	4,460	286	4,440
+ 25	12·2	4,850	21·3	4,850	35·1	4,600	52	4,500	92·5	4,480	146	4,430	210	4,420	287	4,430
+ 30	13	4,500	22·8	4,500	36·7	4,450	53·6	4,350	94·5	4,400	149	4,370	213	4,400	289	4,390
+ 35	13·8	4,200	23·6	4,350	38·2	4,250	54·3	4,300	96	4,300	150	4,320	215	4,350	290	4,360
+ 40	15	3,900	24·8	4,000	39·5	4,130	56	41,160	97·5	4,270	151	4,300	216	4,310	292	4,330

TABLE 11.—*Sag and Stress in Bare Hard Drawn Copper Cables.*

Maximum stress, 17,200 lbs. per square inch (at — 5° C. with additional load); sag (D), in inches; stress (Z), in lbs. per square inch.

Span in Metres.	50		60		80		100		120		140		160		180	
Span in Feet.	163		196		260		326		390		455		520		585	
Temperature ° C.	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z
— 20	9·5	17,200	15·2	15,500	35·7	11,600	67	9,600	110	8,500	160	8,000	220	7,600	290	7,300
— 5 (with additional load)	25	17,200	36	17,200	64	17,200	100	17,200	144	17,200	196	17,200	255	17,200	321	17,200
0	12·6	12,700	19	12,400	43·5	9,600	77	8,500	120	7,800	170	7,500	230	7,200	300	7,050
+ 5	13·6	11,900	20	11,600	45	9,200	79	8,200	122	7,700	173	7,400	233	7,150	303	7,000
+ 10	14·6	11,100	21·5	10,900	47·4	8,800	81	8,000	124	7,500	175	7,200	235	7,050	305	6,950
+ 15	15·6	10,400	22·7	10,200	49·4	8,400	83·5	7,700	127	7,400	177	7,150	237	7,000	307	6,900
+ 20	16·6	9,700	24	9,600	51·3	8,100	86	7,600	129	7,200	180	7,050	239	6,900	310	6,800
+ 25	18·2	9,000	25·7	9,100	53·3	7,800	88	7,300	132	7,100	182	6,950	242	6,830	312	6,750
+ 30	19·3	8,400	27	8,600	55·2	7,500	90	7,100	134	7,000	185	6,850	243	6,800	315	6,710
+ 35	20·5	7,900	29	8,100	57	7,200	93	7,000	137	6,800	187	6,780	246	6,700	317	6,690
+ 40	21·7	7,400	30·4	7,700	59·2	7,000	95	6,800	138	6,700	190	6,700	250	6,650	320	6,600

TABLE 12.—*Sag and Stress in Bare Hard Drawn Copper Cables.*

Maximum stress, 23,000 lbs. per square inch (at — 5° C. with additional load); sag (D), in inches; stress (Z), in lbs. per square inch.

Span in Metres.	60		80		100		120		140		160		180		200	
Span in Feet.	196		260		326		390		455		520		585		650	
Temperature ° C.	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z	D	Z
— 20°	10·4	22,200	19·7	21,000	37·4	17,400	62	15,200	95	13,400	138	12,000	147	11,300	237	11,000
— 5° (with additional load)	26·8	23,000	47·6	23,000	75	23,000	108	23,000	146	23,000	191	23,000	243	23,000	300	23,000
0	11·8	20,000	24·8	16,700	46·5	14,700	70·5	13,200	107	11,900	151	11,000	158	10,500	250	10,400
+ 5	13	17,900	26	16,000	46	14,200	74	12,600	110	11,600	154	10,800	161	10,400	252	10,250
+ 10	13·6	17,200	27·3	15,400	48	13,500	76	12,200	113	11,300	157	10,600	164	10,200	255	10,150
+ 15	14·4	16,200	28·8	14,500	50	13,000	78·5	11,900	115	11,000	160	10,400	166	10,000	259	10,000
+ 20	15·2	15,400	30	13,800	52·5	12,400	81	11,400	119	10,700	163	10,200	168	9,850	262	9,800
+ 25	16	14,600	31·2	13,300	55	11,800	84	11,100	121	10,500	166	10,000	171	9,750	265	9,700
+ 30	17	13,700	33	12,600	57	11,400	87	10,800	124	10,200	169	9,800	173	9,600	268	9,600
+ 35	18	13,000	34·4	12,000	59	11,000	89	10,500	128	10,000	173	9,600	175	9,500	272	9,500
+ 40	19	12,300	36·3	11,500	61·5	10,600	91·5	10,200	130	9,750	176	9,400	178	9,300	275	9,350

Effect of Wind Pressure on the Line and its Supports.

In Mid-European countries it is not essential to make any allowance in the stress calculations for wind pressure, as the strongest winds do not generally occur in cold and frosty weather. In special cases where the wind is to be allowed for it is usually taken as exerting a minimum pressure of 30 lbs.* per square foot of effective surface in a horizontal direction.

The weights of the line and any additional load act vertically downwards, so that the total force on the line is the resultant of two forces at right angles to one another as shown in Fig. 14, where g represents the effect of the weight, W the effect of the wind force, and R the resultant of the two.

The force of the wind is not steady, but occurs in gusts, so that the line is set swinging.

The deviation E from the vertical (Fig. 14) is given by the expression

$$E = d \sin \gamma,$$

and

$$R = \sqrt{W^2 + g^2}$$

$$\therefore \sin \gamma = \frac{W}{\sqrt{W^2 + g^2}}$$

and

$$E = \frac{d \times W}{\sqrt{W^2 + g^2}} \quad . \quad . \quad . \quad . \quad 18$$

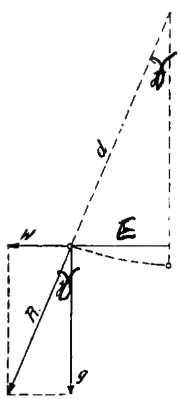


Fig. 14.

This is the result assuming steady conditions, but if anything approaching resonance exists between the frequency of the wind impulses and the natural frequency of the line greater deviations may be produced. The wind pressure W has the effect of an additional load on the supports of the line and acts at the centre of gravity of the area on which it impinges.

If the surface lies normal to the direction of the wind the effective area is equal to the actual area or, in complex building structures, to the sum of the separate areas.

Experiments made by Grashof have shown that the wind pressure w in lbs. per square foot of normal surface is given by the expression : $w = \cdot 0052\, v^2$, where v = wind velocity in miles per hour.

The usual assumption of 30 lbs. per square foot for wind pressure would, therefore, correspond to a wind velocity :

* The Board of Trade rules now allow 25 lbs. (previously 30 lbs.) per square foot of effective area, the effective area for circular sections being taken as $\cdot 6 \times$ diameter $\times$ length.

The General Post Office rules allow 17 lbs. per square foot of effective area, the effective area being taken as $\frac{2}{3} \times$ diameter $\times$ length.

The rules of the Verband Deutscher Elektrotechniker allow 125 kg. per square metre (25·6 lbs. per square foot) of effective area, the effective area being taken as $\cdot 7 \times$ diameter $\times$ length.

In the following pages, in order to be on the safe side, the value of 30 lbs. per square foot of effective area will be used and the effective area for circular sections will be taken as $\cdot 7 \times$ diameter $\times$ length.

$$v = \sqrt{\frac{30}{\cdot0052}} = 76 \text{ miles per hour,}$$

an exceptionally high speed. When the wind strikes a surface F, not normally, but at an angle α, the pressure normal to the surface is, according to Newton,

$$W = w_1 \times F = w \times \sin^2\alpha \times F.$$

If the wind acts on a prism with a rectangular face of length L and breadth A, then, if the direction of the wind is normal to A, the total force on the surface is

$$W = w \times A \times L \quad . \quad . \quad . \quad . \quad . \quad 19$$

If the wind direction lies along the diagonal,

$$W = w \times 2 \times A \times L \times \sin^3 45^\circ = \sqrt{\tfrac{1}{2}} \times w \times A \times L \quad . \quad . \quad 20$$

The wind pressure on a small element $\frac{d}{2}\,d\alpha$ of a cylinder whose axis is normal to the wind direction is :

$$dW = w \sin^3\alpha \frac{d}{2}\,d\alpha,$$

from which :

$$W = w\frac{d}{2}\int_0^\pi \sin^3\alpha\,d\alpha = \frac{2}{3}wd = \cdot667\,wd \quad . \quad . \quad . \quad 21$$

where d is the diameter of the cylinder in feet and W is the total force on a length of cylinder of one foot.

The figure ·667 is usually rounded off to ·7. Using this and putting in the diameter d in inches instead of feet:

Force on 1 foot length of conductor $= W = w \times d \times \frac{\cdot7}{12} = w \times d \times \cdot058.$

Putting in the usual maximum value for $w = 30$ lbs. per square foot, this becomes

inches

$$W = 30 \times d \times \cdot058 = d \times 1\cdot75 \text{ lbs}/\text{ft} \quad . \quad . \quad . \quad 22$$

With cables the surface acted upon by the wind is somewhat greater than that corresponding to the circumscribed circle D. With 7-strand cables the effective diameter is approximately $\frac{4}{3}D$, and with 19-strand ones approximately $\frac{7}{5}D$.

The wind pressure in lbs. per foot run in these cases, therefore, becomes

in inches

$$W = \frac{4}{3} \times D \times 1\cdot75 = D \times 2\cdot35 \quad . \quad . \quad . \quad . \quad 23$$

and

$$W = \frac{7}{5} \times D \times 1\cdot75 = D \times 2\cdot45 \quad . \quad . \quad . \quad . \quad 24$$

where D is the diameter of the circumscribed circle in inches (outer diameter of cable).

EXAMPLE 10.

A 19-strand aluminium cable of ·108 square inch section is suspended with a span of 260 feet. What is the value of the wind pressure on the cable, what is the resultant force due to wind pressure and weight of cable, and how far is the cable driven out of the vertical by the wind if it is assumed that the maximum wind pressure occurs at a temperature of + 10° C., at which temperature the wire has a sag of 37 inches ?

The outer diameter of such a cable will be ·44 inch, so that, by equations 18 and 24 :

$$\text{Total wind force} = W = 2{\cdot}45 \times {\cdot}44 \times 260 = 280 \text{ lbs.}$$

Total weight of cable (by Table 6) :

$$= g = 580 \times \frac{{\cdot}108}{{\cdot}093} \times \frac{260}{5{,}280} \doteq 34 \text{ lbs.}$$

$$\text{Resultant } R = \sqrt{W^2 + g^2} = \sqrt{280^2 + 34^2} = 282 \text{ lbs.}$$

$$\sin \gamma = \frac{W}{R} = \frac{280}{282} = {\cdot}9905$$

$$\gamma = 82° \; 15'$$

$$E = d \sin \gamma = 37 \times {\cdot}9905 = 36{\cdot}7 \text{ inches.}$$

If the same calculation is carried out for a 19-strand copper cable of ·108 square inch section with a sag of 25 inches at 10° C. the following results are obtained :—

$$W = 2{\cdot}45 \times {\cdot}44 \times 260 = 280 \text{ lbs.}$$

$$g = 2{,}280 \times \frac{260}{5{,}280} = 112 \text{ lbs.}$$

$$R = \sqrt{W^2 + g^2} \doteq \sqrt{280^2 + 112^2} = 302 \text{ lbs.}$$

$$\sin \gamma = \frac{W}{R} = \frac{280}{302} = {\cdot}93$$

$$\gamma = 68°$$

$$E = d \sin \gamma = 25 \times {\cdot}93 = 23{\cdot}3 \text{ inches.}$$

It will be seen that the aluminium cable is driven out by the wind force almost twice as far as the copper one. The danger of two neighbouring wires swinging into contact if their synchronism of motion is disturbed is, in fact, considerably greater with aluminium than with copper owing to its lower weight and greater sag.

EXAMPLE 11.

It is required to find the total wind pressure on a wooden pole 29 feet high having a diameter of 8 inches at the top and 12 inches at the ground level. At which height from the ground does this pressure act ? What is the wind pressure effective at the height of the cross-arm placed 27·5 feet above the ground ?

By equation 22 the total pressure on the pole is :

$$W = 1{\cdot}75 \times d \times L = 1{\cdot}75 \times \frac{8 + 12}{2} \times 29 = 510 \text{ lbs.}$$

This force acts at the centre of gravity of the effective surface and, therefore, at a height of

$$\frac{12 + (2 \times 8)}{12 + 8} \times \frac{29}{3} = 13{\cdot}5 \text{ feet from the ground.}$$

The moment of the force is, therefore,

$$M_w = 13{\cdot}5 \times 510 = 6{,}880 \text{ lb.-feet.}$$

The effective pull at the cross-arm at a height of 27·5 feet is :

$$\frac{6{,}880}{27{\cdot}5} = 250 \text{ lbs.}$$

TABLE 13.—*Wind Pressure due to Three Lines, in lbs. per Mast.**

Distance between Masts in Feet.	Cross-section of each line.	Wire ·0093 square inch.	Wire ·0155 square inch.	Wire ·0255 square inch.	Cable ·0255 square inch.	Wire ·039 square inch.	Cable ·039 square inch.	Cable ·054 square inch.	Cable ·078 square inch.	Cable ·108 square inch.
	Diameter of each line.	·11″	·14″	·178″	·2″	·222″	252″	·304″	·364″	·44″
49		28	36	46	52	57	66	78	93	110
98		37	72	92	104	114	132	156	186	220
130		74	96	123	138	153	175	206	250	282
196		112	144	184	206	230	262	312	371	440
260		150	192	245	275	306	350	418	495	586
326		187	240	307	342	384	440	515	620	735
395		224	287	370	410	460	525	620	745	880
490		280	360	460	512	570	680	780	930	1,100
560		315	410	520	585	650	740	880	1,060	1,250
660		370	480	610	685	765	875	1,040	1,240	1,470
980		560	720	920	1,030	1,150	1,320	1,560	1,860	2,200
1,300		745	960	1,220	1,380	1,530	1,750	2,060	2,480	2,950

* Not including the wind pressure on the mast itself.

4. DESIGN OF THE SUPPORTING STRUCTURES.

The various forces acting on the line—tension, weight, and wind pressure—have to be withstood by the structures supporting the line. These three forces act simultaneously, but in different directions, on dead end (or terminal or strain) masts, angle masts, and masts at road, rail, or postal line crossings. Mere supporting masts (intermediate masts), which serve to keep the line off the ground on straight stretches, are not influenced by the tension in the line so long as the lengths of the various spans are equal. On these only the wind pressure on line and mast is effective. Consequently the greatest resisting moment for such masts is not required in the direction of the line, but at right angles to it. In fact, in the direction of the line, these masts should be as flexible as possible. The greater the elasticity in this direction the better and more safely will the one-sided stress, which results from a breakage of the line, be able to distribute itself over a large number of masts and so reduce the overloading of any one mast.

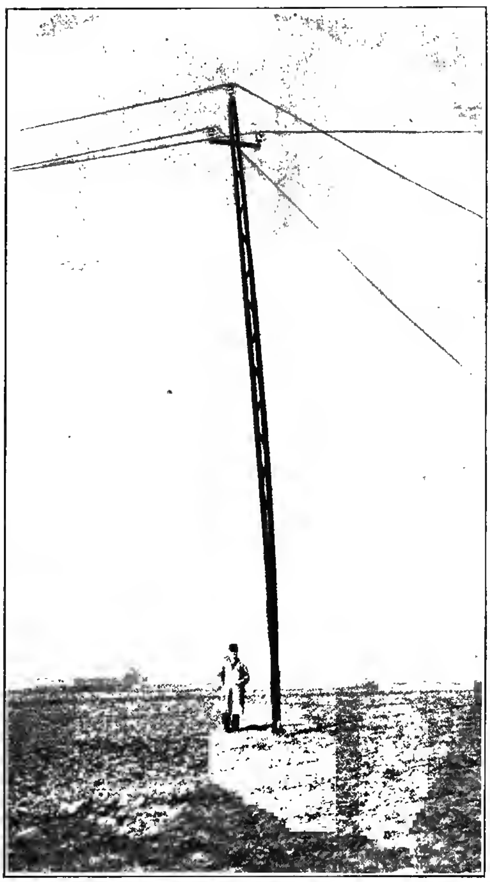


Fig. 15.

The further off a mast is from the point of disturbance the less will its deflection be, and experiment has shown that all appreciable deflection has disappeared by the fourth or fifth mast.

The supporting structures may be subjected to tension, compression, bending, crippling, and twisting forces. The tensile and bending loads are due to the tension of the wires and the wind pressure on line and mast. Compression and crippling (or lateral bending) are due to the weight of the line, and as this is generally very small compared with the other forces special tests in this

direction are not usually necessary. Twisting of a mast may occur when a wire breakage takes place, especially if the cross-arms are long. Elasticity in these masts, particularly in the case of intermediate supporting masts, is a great advantage in this connection again. Fig. 15 is a photograph of an intermediate mast which, in consequence of a breakage of the line, has become twisted through almost 90°. When all the lines were cut clear the mast returned to its original condition without damage.

With regard to the allowable stresses to which overhead structures may be subjected, the rules of the Verband Deutscher Elektrotechniker are a useful guide. These state that for wooden poles the maximum stress is not to exceed 1,000 lbs. per square inch and for iron masts 21,500 lbs. per square inch. Structures of special materials are not to be stressed to values exceeding one-third of the maker's guaranteed breaking stress. Cast-iron structures are not to be subjected to more than 4,300 lbs. per square inch.

The Board of Trade regulations require wooden poles to be designed with a factor of safety of 10 and steel poles with a factor of safety of 6.

Full particulars of wooden poles and their breaking stresses are given in the British Post Office Technical Instructions, XIII. of 1911.

Determination of the Stresses.

The line tension and the wind pressures on line and mast acting at various leverages form the bending moments tending to deflect the mast. The weight of the line together with the vertical components of any of the forces acting at an angle, subject the foundations to compression and crippling (or lateral bending) stresses. Twisting of the supporting structures results from unequal tensions in the lines or from one-sided line breakages.

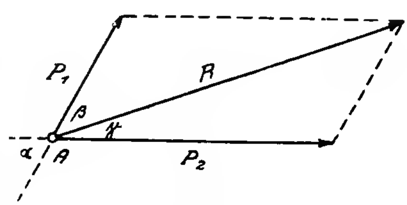


Fig. 16.

Forces acting in the same plane but at different angles can be geometrically added. This addition can be carried out either graphically or analytically. In many cases the graphical method, making use of the polygon of forces, is the simpler and quicker one to use.

The simplest case is that involving the use of the parallelogram of forces. In order to find the resultant of two forces P_1 and P_2 (Fig. 16) acting at a point A, a parallelogram is drawn with the two force vectors as its sides. The diagonal *R* of this figure then gives the resultant force. This single resultant force produces exactly the same effect at the point *A* as the two component forces. In the same way any single force *R* may be split up into two component forces lying in the same plane as *R*. Analytically the resultant can be found by the expression :

$$R = \sqrt{P_1^2 + P_2^2 - 2\, P_1\, P_2 \cos (180 - \alpha)}$$

or, since $\cos (180 - \alpha) = -\cos \alpha$,

$$R = \sqrt{P_1^2 + P_2^2 + 2\, P_1\, P_2 \cos \alpha} \quad . \quad . \quad . \quad . \quad . \quad 25$$

And $\sin \beta : \sin \gamma : \sin \alpha = P_2 : P_1 : R.$

So that the angles between the resultant and the components are found from the expressions :

$$\sin \beta = \frac{P_2}{R} \sin \alpha \; ; \; \sin \gamma = \frac{P_1}{R} \sin \alpha .$$

For the case when $\alpha = 90°$:

$$R = \sqrt{P_1^2 + P_2^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 26$$

and $$\cos \beta = \frac{P_1}{R} ; \; \cos \gamma = \frac{P_2}{R} ; \; \tan \gamma = \frac{P_1}{P_2} .$$

For the case when $P_1 = P_2$:

$$R = P \sqrt{2\,(1 + \cos \alpha)} \; ;$$

and since $$\sqrt{\frac{1 + \cos \alpha}{2}} = \cos \frac{\alpha}{2} \; \therefore \; R = 2\,P \cos \frac{\alpha}{2} \quad . \quad . \quad . \quad . \quad 27$$

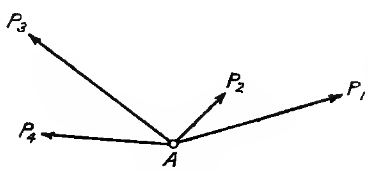


Fig. 17.

When several forces acting at a point are to be added together graphically they are drawn so that the start of one vector coincides with the end of the previous vector. If, for instance, the summation of the four forces P_1 to P_4, acting at the point A (Fig. 17) is to be carried out, a polygon is drawn starting from A and with each vector following the last as stated.

In Fig. 18 :

P_{1-2} is the resultant of P_1 and P_2;
P_{1-3} is the resultant of P_1, P_2 and P_3;
and $R = P_{1-4}$ is the resultant of all four forces.

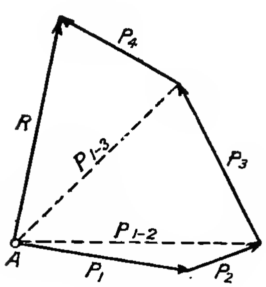


Fig. 18.

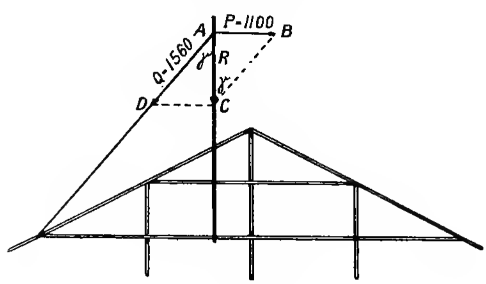


Fig. 19.

Example 12.

The roof pole (Fig. 19) of a local distributing circuit is loaded with a horizontal side pull of 1,100 lbs. At the same point, and at an angle of 45°, an anchoring stay is to be applied. What tension will exist in the stay iron ?

(*a*) *Graphic Solution.*—Draw, to any convenient scale of lbs., the horizontal force 1,100 = AB. From A in the direction of the stay (45°) draw a line to represent the direction of the force in the stay. From the end B of the horizontal force draw a line parallel to the stay direction, and from the point of intersection of this line with the pole draw a line parallel to AB (or P) meeting the stay line at D. Then AD is the force acting on the stay wire, and this measures up as 1,560 lbs.

(*b*) *Analytic solution.*—From Fig. 19 it can be seen that

$$Q = \frac{P}{\sin 45} = \frac{1{,}100}{\cdot 707} = 1{,}560 \text{ lbs.}$$

The forces P and Q form the resultant R, which acts vertically downwards on the pole. The value of R can either be measured off the diagram directly or can be found by the expression

$$R = \frac{P}{\tan 45} = \frac{1{,}100}{1} = 1{,}100 \text{ lbs.}$$

The resultant R is increased by the weight of the line, additional load, and suspension gear, so that the total force compressing the pole is given by the algebraic sum of these items. Fig. 19 shows that as the angle γ diminishes the resultant R increases. When γ is less than 45° R is greater than P. It is advisable, therefore, to keep γ greater than 25°, so that the vertical force shall not be excessive compared with the horizontal force.

Example 13.

A high-tension transmission line alters its direction through 130°. The maximum line tensions acting on the corner mast are 2,320 lbs. and 1,850 lbs. respectively. How great is the resultant of these forces, and at what angle does it act to the greater force ?

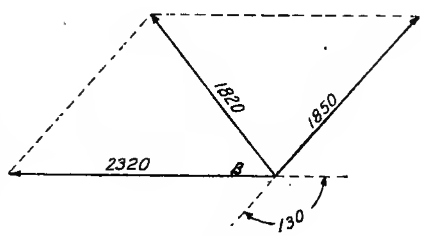


Fig. 20.

(*a*) The graphical solution by means of the parallelogram of forces is shown in Fig. 20. The resultant R is found to be 1,820 lbs., and the angle β between R and P_1 is 51° 35′.

(*b*) By equation 25 :

$$R = \sqrt{P_1^2 + P_2^2 + 2\,P_1\,P_2 \cos \alpha}$$

$$= \sqrt{2{,}320^2 + 1{,}850^2 + 2 \times 2{,}320 \times 1{,}850 \times \cos 130},$$

and $\cos 130° = -\sin 40° \;\therefore\; R = 1{,}820$ lbs.

$$\sin \beta = \frac{P_2}{R} \sin \alpha = \frac{1{,}850}{1{,}820} \times \cdot 766,$$

or $\sin \beta = \cdot 7835$, or $\beta = 51°\ 35'$,

or
$$\cos \beta = \frac{2,320^2 + 1,820^2 - 1,850^2}{2 \times 2,320 \times 1,820} = \cdot 621$$

$$\therefore \beta = 51^\circ\ 35'.$$

EXAMPLE 14.

For the purpose of crossing a river at right angles the direction of a section AB of a H.T. line (three wires of ·054 square inch each) is changed as shown in Fig. 21. The maximum effect on the masts under the most unfavourable conditions is to be investigated.

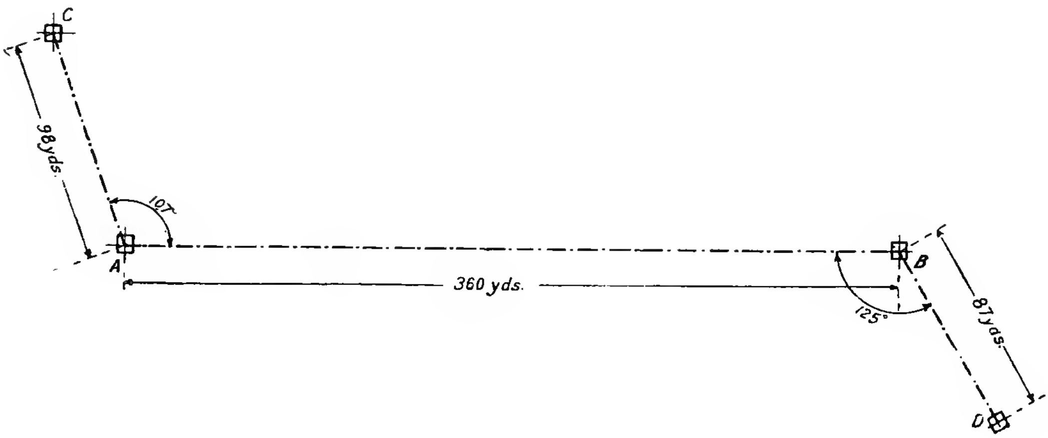


Fig. 21.

The maximum stress in the wires is 23,000 lbs. per square inch.

If all the wires break in one of the neighbouring sections the total load falling on the mast (neglecting the effect of mast deflection) would be :

$$P_1 = 3 \times \cdot 054 \times 23,000 = 3,720 \text{ lbs.}$$

(1) *Determination of the Forces at Mast A.*

The tension in the direction AC may be considered (Fig. 22) as made up of two components, P' and P'', at right angles to one another and acting along the main axes of the mast :

$$P' = P_1 \cos 17^\circ = 3,720 \times \cdot 9563 = 3,550 \text{ lbs.}$$

$$P'' = P_1 \sin 17^\circ = 3,720 \times \cdot 2923 = 1,090 \text{ lbs.}$$

P'' acts in the opposite direction from P_1, so that a resultant remains:

$$P_1 - P'' = 3,720 - 1,090 = 2,630.$$

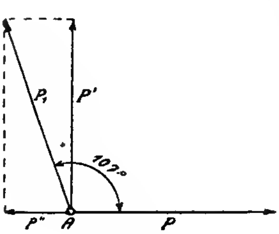


Fig. 22.

There are therefore two forces, P' and $P_1 - P''$, acting at 90° to one another and whose algebraic sum is

$$P' + P_1 - P'' = 3{,}550 + 2{,}630 = 6{,}180 \text{ lbs.}$$

Should all the wires in the crossing become severed the mast will be subjected to the sum of the two forces P' and P'' acting at right angles. The algebraic sum of these forces is :

$$P' + P'' = 3{,}550 + 1{,}090 = 4{,}640 \text{ lbs.}$$

(2) *Determination of the Forces at Mast B.*

The force in the direction BD may be considered as composed of two forces at right angles to one another as shown in Fig. 23. These components are :

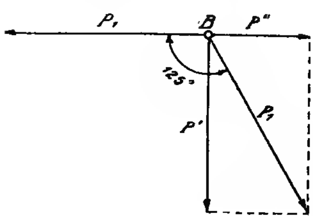


Fig. 23.

$$P' = P_1 \cos 35° = 3{,}720 \times {\cdot}8192 = 3{,}040 \text{ lbs.}$$

and $$P'' = P_1 \sin 35° = 3{,}720 \times {\cdot}5735 = 2{,}130 \text{ lbs.}$$

$$P_1 - P'' = 3{,}720 - 2{,}130 = 1{,}590 \text{ lbs.}$$

The sum of the two forces at right angles to one another is therefore :

$$P' + P_1 - P'' = 3{,}040 + 1{,}590 = 4{,}630 \text{ lbs.}$$

If the wires become severed in the crossing the force on the mast will be that due to the two components P' and P'' at 90° to one another. The algebraic sum of these is

$$3{,}040 + 2{,}130 \text{ lbs.} = 5{,}170 \text{ lbs.}$$

EXAMPLE 15.

At a feeding point on an overhead distributing system five lines branch off as shown in Fig. 24. The five horizontal forces are : $P_1 = 1{,}400$ lbs., $P_2 = 1{,}000$ lbs. $P_3 = 400$ lbs., $P_4 = 2{,}800$ lbs., $P_5 = 1{,}400$ lbs. How great is the resultant force ?

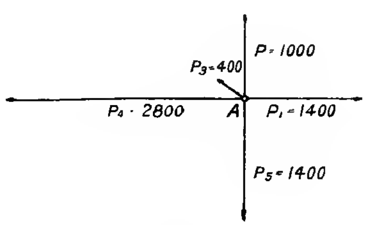


Fig. 24.

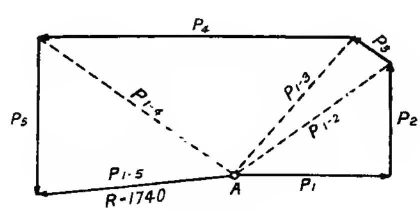


Fig. 24a.

By drawing the polygon of forces (Fig. 24a), to some such scale as 1,000 lbs. to the inch the resultant force is found to be $R = 1{,}740$ lbs. The supporting structure must, therefore, be designed to withstand this force.

TABLE 14.—*Total Pull on "Dead End" or Strain Masts.*

Maximum Stress in the Line Wire in lbs. per square inch.	3 × ·0155 = ·0465 sq. inch.	3 × ·025 = ·075 sq. inch.	3 × ·039 = ·119 sq. inch.	3 × ·054 = ·162 sq. inch.	3 × ·078 = ·234 sq. inch.	3 × ·108 = ·324 sq. inch.	3 × ·148 = ·444 sq. inch.	3 × ·186 = ·558 sq. inch.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
8,600	400	640	1,000	1,400	2,000	2,800	3,800	4,800
11,400	530	850	1,340	1,860	2,670	3,730	5,100	6,400
14,300	670	1,070	1,660	2,340	3,330	4,650	6,300	8,000
17,200	800	1,280	2,000	2,800	4,000	5,600	7,600	9,600
20,000	930	1,500	2,350	3,250	4,650	6,500	8,800	11,200
23,000	1,070	1,700	2,670	3,720	5,300	7,450	10,000	12,800

THE GENERAL LAWS OF MECHANICS.

(*a*) *Tension and Compression.*

If P is the tensile or compressive force acting on a rod of cross section F then

$$P = F \times k \qquad . \quad . \quad . \quad . \quad . \quad . \quad 28$$

where k is the allowable tensile or compressive stress per unit of area for the material.

The strength against tension and compression is approximately the same for many of the materials used in overhead line construction.

The ratio of the maximum possible stress K which the material can stand without breaking to the working stress k is called the factor of safety s:

$$k \times s = K.$$

(*b*) *Compression combined with Bending.*

When a rod subjected to compression is very long compared with its cross-section it will, after a certain force has been exceeded, begin to be deflected out of the straight line and will then be acted upon not only by a compressive stress

Fig. 25.—One end fixed, the other free.

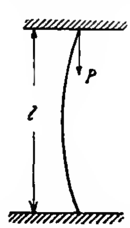


Fig. 26.—Both ends free, and guided in the original axis.

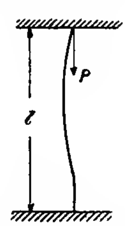


Fig. 27.—One end fixed and the other free, and guided in the original axis.

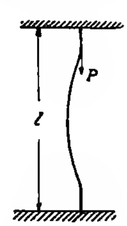


Fig. 28.—Both ends fixed.

k_d but also by a bending stress k_b. If the applied force P is further increased these two stresses will eventually cause collapse.

Euler has deduced the following formulæ for the four arrangements of the ends of the strut shown in Figs. 25 to 28 :—

$$P = \frac{\pi^2}{4}\frac{EJ}{l^2} \quad . \quad . \quad 29$$

(Fig. 25.)

$$P = \pi^2 \frac{EJ}{l^2} \quad . \quad . \quad 30$$

(Fig. 26.)

$$P = 2\,\pi^2 \frac{EJ}{l^2} \quad . \quad . \quad 31$$

(Fig. 27.)

$$P = 4\,\pi^2 \frac{EJ}{l^2} \quad . \quad . \quad 32$$

(Fig. 28.)

where P is the force which can be applied to the strut without collapse.

E is Young's modulus of elasticity, J is the moment of inertia of the section ; and l is the length of the strut.

It will be seen that P is inversely proportional to the square of the length l and, therefore, falls rapidly as the length increases. There is a certain critical length of strut l' for which the resisting power against direct crushing is equal to that against collapse through lateral bending (crumpling). If K_d is the maximum stress which the material can stand under compression and F is the cross-sectional area of the strut, then $F \times K_d$ is the maximum total compressive force. Equating this to the rupturing force given by Euler's formula (29) :

$$\frac{\pi^2}{4}\frac{EJ}{l^2} = FK_d,$$

from which the critical length is found to be

$$l' = \frac{\pi}{2}\sqrt{\frac{EJ}{FK_d}} \quad . \quad . \quad . \quad . \quad . \quad 29a$$

In the same way for the formulæ 30, 31, and 32 :—

$$l' = \pi\sqrt{\frac{EJ}{FK_d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad 30a$$

$$l' = 1{\cdot}41\,\pi\sqrt{\frac{EJ}{FK_d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad 31a$$

$$l' = 2\,\pi\sqrt{\frac{EJ}{FK_d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad 32a$$

(c) *Bending Stress.*

The maximum bending moment M must not exceed the product of the resisting moment W of the cross-section and the safe working value of the bending stress k_b for the material used.

The bending moment is equal to the applied force P multiplied by the length of lever arm L at which it acts, *i.e.*, the perpendicular distance between the line along which the force acts and the fulcrum or turning point.

The resisting moment, or modulus of section, of a cross-sectional area with reference to its neutral axis is equal to the moment of inertia with reference to this axis divided by the distance e of the outermost fibres from the same axis.

So that

$$PL = M = W \times k_b = \frac{J}{e} k_b \qquad . \quad . \quad . \quad . \quad . \quad 33$$

The moment of inertia J_a of a section with reference to any given axis is equal to the moment of inertia with reference to a parallel axis drawn through the centre of gravity (centre of figure) increased by a quantity equal to the area F multiplied by the square of the distance a between the two axes :—

$$J_a = J + F \times a^2 \qquad . \quad . \quad . \quad . \quad . \quad . \quad 34$$

The safe working bending stress k_b must, as in the case of the tensile and compressive stresses, be kept sufficiently far below the elastic limit to avoid any danger of permanent set occurring.

From the equation $M = W \times k_b$, the value of $k_b = \frac{M}{W} = \frac{P \times L}{W}$ is found.

If the resisting moment is alike for all the cross-sections the maximum stress produced at the various cross-sections will be different because the bending moment changes with the length of leverage. If the stress is to be the same at all cross-sections the resisting moments must change in the same way as the bending moments. Supports specially shaped in this way are called beams of constant bending stress, or beams of uniform strength (see Table 15 for examples).

(*d*) *Shearing Stress.*

The resistance of a body to shearing stress is proportional to its cross-section. If k_s is the maximum allowable shearing stress then

$$P = F \times k_s \qquad . \quad . \quad . \quad . \quad . \quad . \quad 35$$

The safe working shear stress k_s is dependent on the shape of the cross-section and should, in general, not exceed two-thirds to four-fifths of k_z, where k_z is the allowable tensile stress for the material.

(*e*) *Torsional Stress.*

The twisting moment $P \times L$, where P is the force applied and L the leverage at which it acts, is equal to the polar resisting moment (or modulus of section with respect to torsion) W_d which the body offers to twisting, multiplied by the allowable stress k_d.

$$M_d = P \times L = W_d \times k_d \qquad . \quad . \quad . \quad . \quad . \quad 36$$

The plane of action of the twisting moment M_d is at right angles to the axis of the body, so that no bending component exists.

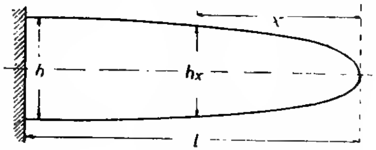
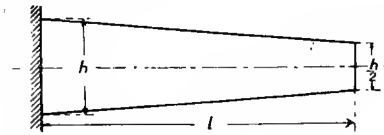
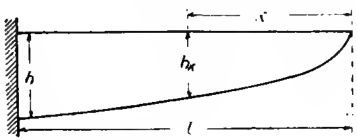
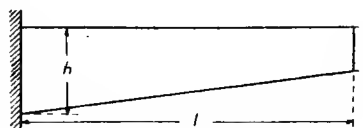
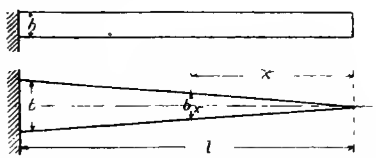
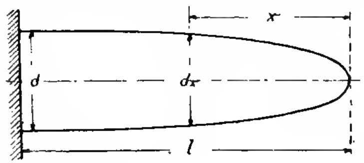
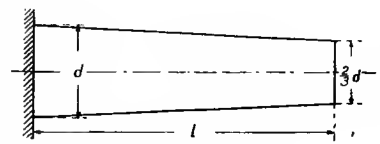
For a circular section

$$W_d = \frac{\pi d^3}{16}.$$

For an annular section having an inner diameter d_1 and an outer diameter d:

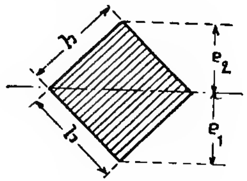
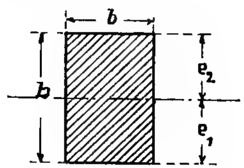
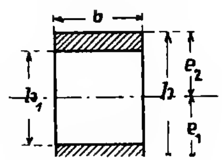
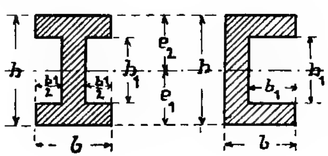
$$W_d = \frac{\pi}{16} \frac{d^4 - d_1^4}{d}.$$

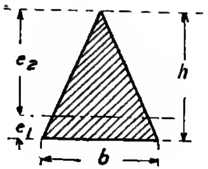
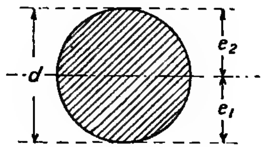
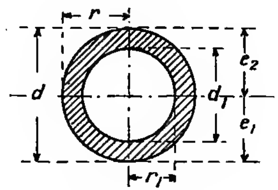
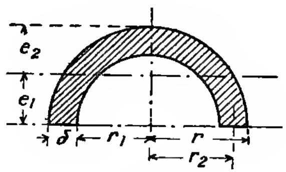
Tab. 15. Beam Shapes giving Constant Bending Stress at all sections.

Exact Shape.	Perimeter of Longitudinal Section.	Approximate Shape.	Formula for Calculating the Cross Section.	Volume of the exact shape.	Volume of the approx. shape.
	Plain Parabola.		Width of Beam b Constant. $h_x = h\sqrt{\frac{x}{l}}$; $h_x = \sqrt{\frac{6\,P\,x}{b\,k_b}}$	$\frac{8}{12}\,b\,h\,l$	$\frac{9}{12}\,b\,h\,l$
	Straight line above Plain Parabola below.		Width of Beam b Constant. $h_x = h\sqrt{\frac{x}{l}}$; $h_x = \sqrt{\frac{6\,P\,x}{b\,k_b}}$	$\frac{8}{12}\,b\,h\,l$	$\frac{9}{12}\,b\,h\,l$
	Straight Line	The exact shape is easily obtainable.	Depth of Beam h Constant. $b_x = b\,\frac{x}{l}$; $b_x = \frac{6\,P\,x}{h^2\,k_b}$	$\frac{1}{2}\,b\,h\,l$	—
	Cubic Parabola		Circular Cross Section $d_x = d\sqrt[3]{\frac{x}{l}}$; $d_x = \sqrt[3]{\frac{32\,P\,x}{\pi \cdot k_b}}$	$\frac{1}{2}\,l\,d^2$	$\frac{5}{9}\,l\,d^2$

The load is applied at the end of the beam.

TABLE 16. MOMENTS OF INERTIA AND RESISTING MOMENTS OF SIMPLE SECTIONS.

Transverse Section.	Moment of Inertia.	Resisting Moment.	Position of Centre of Gravity.	Area of Cross-section.
	$J = \frac{h^4}{12}$	$W = \frac{\sqrt{2}}{12} h^3 = 0{,}1179\, h^3$	$e_1 = e_2 = \frac{h}{\sqrt{2}}$	h^2
	$J = \frac{b\, h^3}{12}$	$W = \frac{b\, h^2}{6}$	$e_1 = e_2 = \frac{h}{2}$	$b\, h$
	$J = \frac{b}{12} (h^3 - h_1^3)$	$W = \frac{b}{6}\, \frac{h^3 - h_1^3}{h}$	$e_1 = e_2 = \frac{h}{2}$	$b\, (h - h_1)$
	$J = \frac{b\, h^3 - b_1\, h_1^3}{12}$	$W = \frac{b\, h^3 - b_1\, h_1^3}{6\, h}$	$e_1 = e_2 = \frac{h}{2}$	$b\, h - b_1\, h_1$

	$J = \frac{b\,h^3}{36}$	$W = \frac{b\,h^2}{24}$	$e_1 = \frac{1}{3}h$ $e_2 = \frac{2}{3}h$	$\frac{b\,h}{2}$
	$J = \frac{\pi\,d^4}{64} = \frac{\pi\,r^4}{4}$ $= \backsim 0{,}05 d^4$	$W = \frac{\pi\,d^3}{32} = \frac{\pi\,r^3}{4}$ $= \backsim\ 0{,}1\ d^3$	$e_1 = e_2 = \frac{d}{2}$	$\frac{\pi\,d^2}{4}$
	$J = \frac{\pi}{64}(d^4 - d_1^4)$ $= \frac{\pi}{4}(r^4 - r_1^4)$ $= \backsim 0{,}05\,(d^4 - d_1^4)$	$W = \frac{\pi}{32}\,\frac{d^4 - d_1^4}{d}$ $= \frac{\pi}{4}\,\frac{r^4 - r_1^4}{r}$ $= \backsim\ 0{,}1\ \frac{d^4 - d_1^4}{d}$	$e_1 = e_2 = \frac{d}{2}$	$\frac{\pi}{4}(d^2 - d_1^2)$
	$J = 0{,}1098\,(r^4 - r_1^4)$ $- \frac{0{,}283\,r^2 r_1^2 (r - r_1)}{r + r_1}$	—	$e_1 = \frac{4}{3\,\pi}\,\frac{r^2 + r\,r_1 + r_1^2}{r + r_1}$ $= \frac{4}{3\,\pi}\,\frac{r^3 - r_1^3}{r^2 - r_1^2}$ $e_2 = r - e_1$	$\frac{\pi}{2}(r^2 - r_1^2)$

Special Cases.

(a) *Independent Pole.*

By equation 33 :

$$M = W \times k_b.$$

The resisting moment (or modulus of section) of a circular cross-section is

$$W = \frac{\pi}{32} \times d^3,$$

so that

$$M = \frac{\pi}{32} d^3 k_b = P \times L,$$

where L is the length between the ground level and the point at which the force acts, and P is the force acting with the leverage L.

The maximum diameter D_u at the ground level is then

$$D_u = 2{\cdot}15 \sqrt[3]{\frac{P \times L}{k_b}} \quad . \quad . \quad . \quad . \quad . \quad 37$$

The required outline for the longitudinal cross-section of the beam to give a constant bending stress all the way up can be shown to be a cubic parabola. The approximate straight line outline corresponding to this is a beam having a diameter D_o at the top equal to $\frac{2}{3} D_u$, or

$$D_u = \frac{3}{2} D_o \quad . \quad . \quad . \quad . \quad . \quad . \quad 38$$

From this it follows that for wooden poles having considerable taper it is not the actual diameter of the ground level which should be used in the formula, but rather that diameter which is given by $D_u = \frac{3}{2} D_o$. With poles whose diameter (D_u) at the ground level is less than $\frac{3}{2} D_o$ the maximum stress occurs slightly below the ground level. For all practical purposes, however, it is sufficiently accurate to deal with the diameter at the ground level.

Besides the bending stress, due to the line tension and the wind pressure on line and mast, a vertical load also exists due to the weight of the line wire (together with any additional load), the weight of the insulators and fittings, the weight of the mast itself, and the vertical components of any forces or reactions applied at an angle to the horizontal. These forces acting in the direction of the mast axis subject it to crushing and lateral bending stresses. The critical length of mast can be found by the use of formula 29 (a). For a circular cross-section the moment of inertia $J = \frac{\pi}{64} d^4$. Inserting this value in formula 29 (a) the critical length of pole is found as :

$$l' = \frac{\pi d}{8} \sqrt{\frac{E}{Kd}}$$

For a pole diameter of $8\frac{3}{4}$ inches for instance, and a material having a maximum safe compressive stress of 4,600 lbs. per square inch $= K_d$, and for which Young's modulus is $1{\cdot}5 \times 10^6$ lbs. per square inch, the critical length

$$l' = \frac{3{\cdot}14 \times 8\frac{3}{4}}{8}\sqrt{\frac{1{\cdot}5 \times 10^6}{4{,}600}} = 62 \text{ inches.}$$

This shows that for all wooden masts likely to be used in overhead line construction the resisting power against lateral bending is less than that against direct crushing.

For an iron tubular mast the moment of inertia is

$$J = \frac{\pi}{64}(d^4 - d_1{}^4),$$

where d is the outer and d_1 the inner diameter.

By equation 29 (a) the critical length : l', taking $d = 3$ inches, $d_1 = 2\frac{3}{4}$ inches, $E = 30{\cdot}7 \times 10^6$ lbs. per square inch and $K_d = 47{,}000$ lbs. per square inch, for wrought iron, is :

$$l' = \frac{\pi}{2}\sqrt{\frac{30{\cdot}7 \times 10^6 \times {\cdot}05\,(3^4 - 2{\cdot}75^4)}{{\cdot}785 \times (3^2 - 2{\cdot}75^2) \times 47{,}000}} = 42 \text{ inches.}$$

If a vertical compressive load P_v exists on the cross-section F at the ground level the total stress will be

$$k = \frac{PL}{W} + \frac{P_v}{F} \quad . \quad . \quad . \quad . \quad . \quad . \qquad 37\,(a)$$

P being the effective sideway pull.

Since the length of all wooden poles exceeds the critical length the danger of lateral bending is more important than that of direct crushing. The allowable stress for this case is *

$$k = \frac{M}{W} - \frac{P_v}{F} \quad . \quad . \quad . \quad . \quad . \quad . \qquad 37\,(b)$$

Here

$$M = \frac{P}{w}\tan wL, \text{ and } w = \sqrt{\frac{P_v}{EJ}} \text{ in radians.}$$

The Verband Deutscher Elektroteckniker lays down the rule that, for wooden poles used on straight stretches of line the diameter of the pole at the top (in centimetres) is to be

$$D_o = 1{\cdot}2\,\sqrt{\Delta L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 39$$

where Δ is the sum of the diameters of all the wires attached to the mast in millimetres and L is the mean height of the wires above the earth in metres. (If Δ is in inches, L in feet, and D_o in inches the expression becomes

$$\boxed{D_o = 1{\cdot}32\,\sqrt{\Delta L}).}$$

In order that the stress at the ground level shall not exceed that at any

* See Hütte, Vol. I., p. 599.

Δ = sum of the ∅ of all wires attached to
L = mean height of wire above earth

other point on the mast the diameter at the ground must, in accordance with equation 38, be

$$D_u = D_o \times \frac{3}{2}.$$

Poles at angle points, at road crossings, and, in general, where special safety is desirable, should be designed so that k_b in equations 37 and 38 does not exceed 1,000 lbs. per square inch.

The application of these rules is indicated by the following examples :—

(*a*) A line is to be erected on wooden poles 24·5 feet high with the mean height of the wire supports 23 feet above the earth. There are to be three copper lines of ·108 square inch sections and ·44 inch outer diameter, and a specific gravity of 9·2 (4 lbs. per foot per square inch), three copper lines of ·078 square inch section and ·36 inch outer diameter and specific gravity of 9·2, and two copper lines of ·025 square inch section and ·175 inch diameter and a specific gravity of 8·9 (3·85 lbs. per foot per square inch). What should be the dimensions of the poles ?

By the rule of the V. D. E.

$$D_o = 1{\cdot}32\sqrt{2{\cdot}75 \times 23} = 10\tfrac{1}{2} \text{ inches,}$$

and
$$D_u = \frac{3}{2} D_o = \frac{3}{2} \times 10\tfrac{1}{2} = 15\tfrac{3}{4} \text{ inches.}$$

The bending load is due to wind pressure on the line and the poles. Taking the span as 130 feet (the maximum allowed by the V. D. E. rules when the total cross-section of the wires exceeds 300 square millimetres or ·47 square inch), the wind pressure is (by equation 22) :

$$\text{On the lines} = 2{\cdot}75 \times 130 \times 1{\cdot}75 = 625 \text{ lbs.}$$

$$\text{On the mast} = \frac{10\frac{1}{2} + 15\frac{3}{4}}{2} \times 24{\cdot}5 \times 1{\cdot}75 = 560 \text{ lbs.}$$

$$\text{On the supports and insulators, say} = 50 \text{ lbs.}$$

The wind pressure on the lines and insulators acts at a height of 23 feet above the earth, whilst the wind pressure on the poles acts at the centre of gravity of these, or at a height of

$$\frac{15\frac{3}{4} + 2 \times 10\frac{1}{2}}{15\frac{3}{4} + 10\frac{1}{2}} \times \frac{24{\cdot}5}{3} = 11{\cdot}4 \text{ feet.}$$

The effective moment acting at a height of 23 feet is therefore

$$\{(625 + 50) \times 23 + (560 \times 11{\cdot}4)\}\ 12 = 263{,}000 \text{ lb.-inches.}$$

By equation 37 the diameter of pole at the ground level, assuming a stress k_b of 1,000 lbs. per square inch, should, therefore, be

$$D_u = 2{\cdot}15\sqrt[3]{\frac{263{,}000}{1{,}000}} = 13{\cdot}8 \text{ inches,}$$

and
$$D_o = \frac{2}{3} \times D_u = \frac{2}{3} \times 13{\cdot}8 = 9{\cdot}2 \text{ inches.}$$

If the diameters found by the rule of the V. D. E. are used in place of these the stress k_b will be less than 1,000 lbs. per square inch, thus :

$$15\tfrac{3}{4} = 2\cdot15\sqrt[3]{\frac{263{,}000}{k_b}}, \text{ or } k_b = 680 \text{ lbs. per square inch.}$$

Taking the maximum possible bending stress for pine to be 6,750 lbs. per square inch, the factor of safety therefore works out

$$\frac{6{,}750}{680} = 10.$$

The force P_v acting vertically along the axis of the pole is made up as follows :

		lbs.
Weight of line wire 130 ($\cdot108 \times 3 \times 4 + \cdot078 \times 3 \times 4 + \cdot025 \times 2 \times 3\cdot85$)	=	315
Additional load $6\cdot6 \times 130$ ($\cdot108 \times 3 + \cdot078 \times 3 + \cdot025 \times 2$)	=	520
Weight of pole above ground level		900
,, ,, insulators and fittings		180
		1,915

By equation 37 (*a*) the total stress is, therefore :

$$k = \frac{263{,}000}{\frac{\pi}{32} \times (15\tfrac{3}{4})^3} + \frac{1{,}915}{(15\tfrac{3}{4})^2 \times \cdot785} = 695 \text{ lbs. per square inch.}$$

If the smaller diameter of 13·8 inches had been used the total stress would have worked out at

$$k = \frac{\{(625 + 50)\,23 + (490 \times 11\cdot4)\}\,12}{\frac{\pi}{32}\,(13\cdot8)^3} + \frac{1{,}600}{(13\cdot8)^2 \times \cdot785} = \begin{cases}990 \text{ lbs. per} \\ \text{square inch.}\end{cases}$$

By equation 37 (*b*) the stress, taking into account the load P_v tending to produce lateral bending, is found as follows :

Using the larger pole of $15\frac{3}{4}$ inches diameter :

$$k = \frac{M}{\frac{\pi}{32}\,(15\tfrac{3}{4})^3} - \frac{1{,}915}{(15\tfrac{3}{4})^2 \times \cdot785}$$

where $$M = \frac{P}{w} \tan wL, \text{ and } w = \sqrt{\frac{P_v}{EJ}}$$

$$\therefore w = \sqrt{\frac{1{,}915}{1\cdot5 \times 10^6 \times (\cdot05 \times (15\tfrac{3}{4})^4)}} = \cdot00065,$$

$$\therefore \tan w \times L = \tan \cdot00065 \times 23 \times 12 = \tan \cdot18 = \cdot18 \text{ practically.}$$

P, the effective sideway pull due to the wind,

$$= (625 + 50) + 560 \times \frac{11 \cdot 4}{23} = 1{,}053 \text{ lbs.}$$

$$\therefore k = \frac{1{,}053 \times \cdot 18}{\cdot 00065 \times \frac{\pi}{32} \times (15\frac{3}{4})^3} - \frac{1{,}915}{(15\frac{3}{4})^2 \times \cdot 785} \doteq 750 \text{ lbs. per square inch.}$$

In the same way for the smaller mast of diameter 13·8 inches :—

$$k = 950 \text{ lbs. per square inch.}$$

Even in this case the factor of safety is

$$\frac{6{,}750}{950} = 7 \cdot 1.$$

(*b*) Three copper lines, each of ·054 square inch section, and outer diameter of ·3 inch and specific gravity of 9·2 (4 lbs. per foot per square inch), are to be erected on wooden poles situated 260 feet apart. The insulators are mounted on angle pins screwed into the poles. The poles are 27·5 feet high and the mean height of the lines is 26 feet. What diameter should the poles be made ?

Using the V. D. E. rule the diameter at the top should be :

$$D_o = 1 \cdot 32 \sqrt{\Delta L} = 1 \cdot 32 \sqrt{\cdot 9 \times 26} = 6 \cdot 4 \text{ inches,}$$

and

$$D_u = \frac{3}{2} D_o = 9 \cdot 6 \text{ inches.}$$

Wind pressure on the lines $= \cdot 9 \times 260 \times 1 \cdot 75 = 410$ lbs.

" " " pole $= \frac{6 \cdot 4 + 9 \cdot 6}{2} \times 27 \cdot 5 \times 1 \cdot 75 = 385$ lbs.

Leverage for the wind pressure on the line $= 26$ feet.

" " " " " pole $= 13$ feet.

Bending moment $M = \{410 \times 26 + 385 \times 13\}\ 12 = 186{,}000$ lb.-inches.

Using equation 37 the diameter at the ground level would work out at :

$$D_u = 2 \cdot 15 \sqrt[3]{\frac{186{,}000}{1{,}000}} = 12 \cdot 2 \text{ inches,}$$

and

$$D_o = \frac{2}{3} D_u = 8 \cdot 1 \text{ inches.}$$

If the diameter found by the V. D. E. rule is used the working stress k would be found as follows :

$$9 \cdot 6 = 2 \cdot 15 \sqrt[3]{\frac{186{,}000}{k}},$$

from which $k = 1{,}920$ lbs. per square inch.

The factor of safety would be

$$\frac{6{,}750}{1{,}920} = 3 \cdot 5.$$

		lbs.
The weight of the lines $= \cdot054 \times 3 \times 4 \times 260$	$=$	168
Additional load $= 6\cdot6 \times \cdot054 \times 3 \times 260$	$=$	276
Weight of pole above ground	$=$	376
,, ,, insulators and fittings . . .	$=$	20
	$P_v =$	840

By equation 37 (*a*) :

$$k = \frac{186{,}000}{\frac{\pi}{32} \times 9\cdot6^3} + \frac{840}{(9\cdot6)^2 \times \cdot785} = \frac{186{,}000}{86} + \frac{840}{72} = 2{,}180 \text{ lbs. per square inch.}$$

If the larger diameter of 12·2 inches were used :

$$k = \frac{\{410 \times 26 + 470 \times 13\}\ 12}{176} + \frac{970}{116} = 1{,}140 \text{ lbs. per square inch.}$$

Applying equation 37 (*b*) the results for the smaller pole are :

$$k = \frac{M}{86} - \frac{840}{72};\ w = \sqrt{\frac{840}{1\cdot5 \times 10^6 \times 440}} = \cdot00115$$

$$\tan w \times L = \tan \cdot00115 \times 26 \times 12 = \cdot36 \text{ practically.}$$

$$\therefore k = \frac{\left(410 + 385 \times \frac{13}{26}\right) + \cdot36}{\cdot00115 \times 86} - \frac{840}{72} = 2{,}170 \text{ lbs. per square inch.}$$

For the thicker pole :

$$k = \frac{M}{176} - \frac{970}{116};\ w = \sqrt{\frac{970}{65 \times 10^6 \times 1{,}120}} = \cdot00076$$

$$\tan w \times L = \tan \cdot00076 \times 26 \times 12 = \cdot237 \text{ practically.}$$

$$\therefore k = \frac{\left(410 + 490 \times \frac{13}{26}\right) \times \cdot237}{\cdot00076 \times 176} - \frac{970}{116} = 1{,}145 \text{ lbs. per square inch.}$$

Summary of Results.

	Calculated Values of Stress in lbs. per square inch.			
	Bending by Equation 37.	Bending and Compression by Equation 37 (*a*).	Lateral Bending by Equation 37 (*b*).	Using the Dimensions given by the V. D. E. Rule.
Example (*a*) . .	1,000	990	950	695
Example (*b*) . .	1,000	1,140	1,145	2,180

The above summary shows that in all those cases for which wooden poles would be likely to be used the calculation by means of the simple bending equation (37) gives sufficient accuracy. The vertical loading is, with the factors of safety usually employed, quite negligible both as regards plain compression and as regards the lateral bending effect.

The actual stress in example (*a*) is a little lower and in example (*b*) a little higher than the standard figure assumed (1,000 lbs. per square inch), but the differences are unimportant.

The rule of the V. D. E., on the other hand, shows large deviations, but in connection with this it may be pointed out that usually the taper of wooden poles is not so great as that indicated by the rule. An average taper is 1 inch in about 8 feet. Thus in example (*a*) the pole having a top diameter of $10\frac{1}{2}$ inches would have a butt diameter of $10\frac{1}{2} + \left(1 \times \frac{23}{8}\right) = 13{\cdot}4$ inches instead of $15\frac{3}{4}$ inches, whilst the correct diameter for a stress of 1,000 lbs. per square inch is, by equation 37, 13·8 inches—a fairly close agreement.

In example (*b*) the V. D. E. rule gives a smaller pole than equation 37, and at the same time the taper is quite normal; consequently in this case the pole would actually have the excess load. A line such as this with spans of 260 feet would probably not be worked at less than 1,000 volts, and in that case the V. D. E. rules specify a minimum top diameter of 7·1 inches, and this would partly get over the difficulty. At the same time there is no serious objection to working with a stress of 1,300 to 1,500 lbs. per square inch, as there would still be a factor of safety of $4\frac{1}{2}$ or 5, which is ample, even allowing for the unavoidable deterioration of wooden poles with time.

A single unsupported wooden pole is only suitable for comparatively small loads. At angle points and in windy districts, or for heavy lines, the stability must be increased by means of stays or struts, or double masts of A form (Fig. 31) or H form (Fig. 32) can be used.

(*b*) *Stayed Poles.*

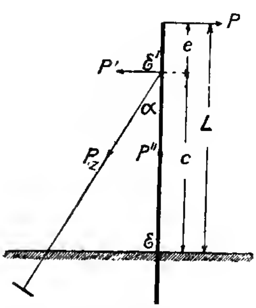


Fig. 29.

Using the lettering shown on Fig. 29, the couple with regard to the fulcrum E is :

$$P'c = P\,(e + c)$$
$$P' = P\left(1 + \frac{e}{c}\right).$$

The relation is only accurate if the pole is free to swivel on the point E. As, however, the pole is let into the earth this does not hold and an additional resisting moment M_e for the ground effect must be taken into account. The above equation will not serve for the determination of the unknown M_e, so that the value of P′ must be obtained from P by another procedure. P' is to have such an amount and direction as to prevent the point E'

on the pole deviating from the vertical. Consequently the bending tendencies due to P and P' must be equal and opposite at the point E'. For simplicity the cross-section of the pole will be assumed to be uniform. The bending deflection produced by the force P at the point E' will then be*

$$f = \frac{PL^3}{2\,EJ}\left(\frac{c^2}{L} - \frac{1}{3}\frac{c^3}{L^3}\right)$$

P' produces the deflection

$$f = \frac{P'}{EJ} \times \frac{c^3}{3}$$

Equating the two deflections and putting $L = e + c$:

$$P' = P\left(1 + \frac{3}{2}\frac{e}{c}\right).$$

The tension P_z in the stay wire is found from the equation

$$P' = P_z \sin \alpha$$

or

$$P_z = \frac{P'}{\sin \alpha} = \frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right) = F \times k_z \quad . \quad . \quad . \quad 40$$

For a stay of circular iron wire or rod the diameter is:

$$d = 1{\cdot}13\sqrt{\frac{P}{k_z \sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right)} \quad . \quad . \quad . \quad . \quad 41$$

Taking k_z as 21,500 lbs. per square inch for wrought iron this becomes:

$$d = {\cdot}0077\sqrt{\frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right)} \quad . \quad . \quad . \quad 41\,(a)$$

If iron wire with an allowable working stress of 28,500 lbs. per square inch is used the total cross-sectional area of these stay wires must be:

$$F = {\cdot}000035 \times \frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right) \quad . \quad . \quad . \quad 41\,(b)$$

The pole will experience its maximum stress at E' where the three stresses due to (1) the line tension $= \frac{P \times e}{W}$, (2) the vertical component of the stay wire tension $= \frac{P' \cos \alpha}{F}$, and (3) the weight of the line with additional load, insulators and fittings $= \frac{P_v}{F}$ all add up.

The total stress at this dangerous section is thus:

$$k = \frac{P \times e}{W} + \frac{1}{F}\left\{P\left(1 + \frac{3}{2}\frac{e}{c}\right)\cos \alpha + P_v\right\} \quad . \quad . \quad . \quad 42$$

* See Hütte, 21st edition, Part I., p. 565.

For wooden poles of circular section this becomes :

$$k = \frac{10 \times P \times e}{D^3} + \frac{1{\cdot}27}{D^2}\left\{P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha + P_v\right\} \quad . \qquad 42\,(a)$$

The vertical forces subject the part of the pole $E\,E'$ of length c to a tendency to lateral bending (crumpling) if c exceeds the critical length. Since the foot of the pole is practically fixed whilst the point E' is free, the third of Euler's equations (31) applies:

$$P = 2\,\pi^2\,\frac{E \times J}{L^2} = \text{maximum allowable compressive force.}$$

Putting c for L and the whole vertical load for P in this equation, the necessary moment of inertia in the above case is, therefore, found to be:

$$J = \frac{c^2}{2\,\pi^2\,E}\left\{P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha + P_v\right\} \quad . \quad . \quad . \quad 43$$

and for a pole of circular section :

$$J = \frac{\pi}{64}\,D^4,$$

$$\therefore D = \sqrt[4]{\frac{c^2}{E}\left\{P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha + P_r\right\}} \quad . \quad . \quad . \quad 44$$

For pinewood and allowing a factor of safety of 6 against lateral bending the smallest allowable diameter in inches works out at

$$D = \sqrt[4]{\frac{c^2 \times 6}{1{\cdot}5 \times 10^6}\left\{P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha + P_v\right\}}$$

$$= {\cdot}045\,\sqrt[4]{c^2\left\{P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha + P_v\right\}} \quad . \quad . \qquad 44\,(a)$$

(c) *Strutted Poles.*

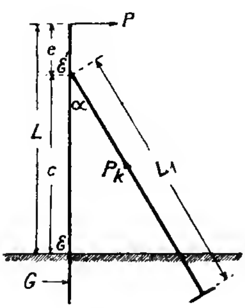


Fig. 30.

This arrangement is shown diagrammatically in Fig. 30. The compressive force P_k on the strut is the same as the tensile force on the stay in the last case, viz. :

$$P_k = \frac{P}{\sin\alpha}\left(1 + \frac{3\,e}{2\,c}\right) \quad . \quad . \quad . \quad 45$$

The upper end of the strut may be considered as free to move and the lower one as fixed, but, since the latter assumption is not strictly correct, it is advisable to include the full length L_1 of the strut in the calculation. The minimum diameter of strut is then found as :

$$D = \sqrt[4]{\frac{PL_1^2}{E\sin\alpha}\left(1 + \frac{3\,e}{2\,c}\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad 46$$

which for pinewood with a factor of safety of 6 works out at

$$D = {\cdot}045 \times \sqrt[4]{\frac{PL_1^2}{\sin\alpha}\left(1 + \frac{3\,e}{2\,c}\right)} \quad . \quad . \quad . \qquad 46\,(a)$$

The vertical component of the force P_k on the strut acts upwards instead of downwards, as in the case of the stay. Consequently it acts in opposition to the bending moment and the weight of the line. The stress at the dangerous section E' is, in accordance with equations 42 and 42 (*a*) :

$$k = \frac{P \times e}{W} + \frac{1}{F}\left\{P_v - P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha\right\} \quad . \quad . \quad . \quad . \quad 47$$

$$k = \frac{10 \times P \times e}{D^3} + \frac{1{\cdot}27}{D^2}\left\{P_v - P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha\right\} \quad . \quad 47\,(a)$$

The stress on the portion of the pole below E' due to the vertical force P_v is found in an analogous manner to that used for equations 44 and 44 (*a*), so that :

$$D = \sqrt[4]{\frac{c^2}{E}\left\{P_v - P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha\right\}} \quad . \quad . \quad . \quad . \quad 48$$

and

$$D = {\cdot}045\sqrt[4]{c^2\left\{P_v - P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha\right\}} \quad . \quad . \quad 48\,(a)$$

If the dangerous section at E' is not weakened by the attachment of the strut the strutted pole can be more heavily loaded than the stayed pole, other things being equal.

The slanting upwardly-directed force due to the strut may, under unfavourable conditions (acute angle α), be great enough to lift the pole out of the ground. In such cases (especially if the soil is sandy and insecure) the foot of the pole must be specially anchored in the ground, or pole and strut must be bound together by a cross-bolt. Such a bolt, introduced about half-way up, also reduces the risk of lateral bending by shortening the free length.

(*d*) *Double Pole of A form.*

The strength of such an A pole, as is shown in Fig. 31, depends on its power to resist lateral bending by compression when the resultant horizontal force acts in the line joining the two pole centres.

If P is the horizontal force in lbs. acting at the head of the pole,

L is the length of the pole in inches from the point of action at the top to the cross-piece below the ground level, and

A is the distance between the pole centres at the point where the cross-piece is fitted, in inches,

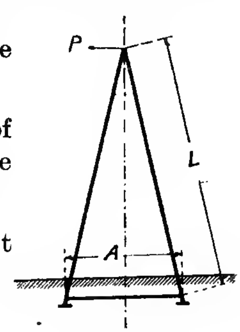


Fig. 31.

then the lateral bending force acting on the pole is :

$$P_k = \frac{P \times L}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 49$$

Inserting this value for P_k and the value for the moment of inertia of a circular section wooden pole $\left(\frac{\pi}{64} D^4\right)$ in Euler's equation, the result is

$$D = \sqrt[4]{\frac{P \times L^3}{A E}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 50$$

For pinewood with a factor of safety of 6 this becomes

$$D = \cdot 045 \sqrt[4]{\frac{P \times L^3}{A}} \quad . \quad . \quad . \quad . \quad . \quad 50\,(a)$$

If the two poles are connected by a tie-bar half or one-third the way up, the free length is reduced and the resistance of the system to lateral bending is greatly increased.

In the above discussion the vertical force P_v, due to the weight of the line and fittings, has not been considered. If α is the angle which each pole forms with the vertical, the force on each pole will be

$$P_v' = \frac{P_v}{2 \times \cos \alpha}.$$

This force combines with the lateral bending force to give a total of

$$P_k' = \frac{P \times L}{A} + \frac{P_v}{2 \cos \alpha} \quad . \quad . \quad . \quad . \quad . \quad 51$$

P_v' is usually so small compared with P_k that it can safely be neglected.

(*e*) *Double Pole of H Form.*

This arrangement is shown in Fig. 32. The total horizontal force is divided equally between the two poles, each being acted upon by $\frac{P}{2}$. The tie bolt V, with the strut or truss-rod s arranged as shown, is subjected to a tensile force of

$$P' = \frac{P}{2}\left(1 + \frac{3}{2}\frac{e}{c}\right).$$

The force tending to bend the diagonal strut s laterally is, by equation 45,

$$P_k = 2\,\frac{\frac{P}{2}\left(1 + \frac{3}{2}\frac{e}{c}\right)}{\sin \alpha} = \frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right) \quad . \quad . \quad 52$$

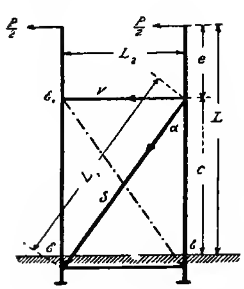


Fig. 32.

If the diagonal truss-rod were placed as shown dotted in Fig. 32 it would be subjected to a tensile stress whilst the cross-bolt V would receive a compressive stress. If both truss-rods are fitted the cross-bolt V remains unstressed and can be omitted without weakening the structure.

The stress on the dangerous section of the pole at E_1 depends on the arrangement adopted. If the crossed truss-rods are used the stress, according to equations 42 and 47, will be :

$$k = \frac{P \times e}{2\,W} + \frac{1}{F}\left\{\frac{P_v}{2} \pm P\left(1 + \frac{3\,e}{2\,c}\right)\cos\alpha\right\} \quad . \quad . \quad . \quad 53$$

If only one truss-rod and the cross-bar V are used the unsupported mast remains unaffected by the vertical component of the lateral force on the truss-rod, so that

$$k = \frac{P \times e}{2\,W} + \frac{P_v}{2\,F} \quad . \quad . \quad . \quad . \quad . \quad 54$$

EXAMPLE 16.

The terminal stretch of an overhead distributing line consisting of two wires of ·025 square inch each is to be strained to a pole 23 feet high. The position of the pole prevents the use of stays or struts. What diameter at the top and at the base should the pole have ? The maximum tension in the line is 11,500 lbs. per square inch.

The force acting on the pole 23 feet above the ground is

$$P = 2 \times {\cdot}025 \times 11{,}500 = 575 \text{ lbs.}$$

By equation 37, for a maximum bending stress of 1,000 lbs. per square inch, the diameter at the base of the pole is

$$D_u = 2{\cdot}15\sqrt[3]{\frac{575 \times 23 \times 12}{1{,}000}} = 11{\cdot}6 \text{ inches.}$$

$$D_o = \frac{2}{3}\,D_u = 7{\cdot}75 \text{ inches.}$$

EXAMPLE 17.

The overhead service leads to a small works consist of three wires each of ·039 square inch and one wire of ·0155 square inch section. The lines end at an iron wall post of the form shown in Fig. 33. What must the resisting moment of the dangerous section at E be to make the post self-supporting, and what cross-sections should be used ?

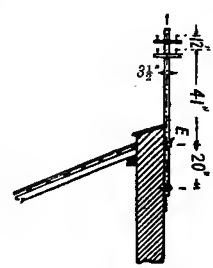


Fig. 33.

The force on the whole of the lines may be taken as acting midway between the cross-arms and consequently at a leverage of 41 + 6 = 47 inches.

Taking the line tension as 11,500 lbs. per square inch the bending moment

$$M = P \times L = 11{,}500\,(3 \times {\cdot}039 + 1 \times {\cdot}0155)\,47$$
$$= 71{,}000 \text{ lb.-inches.}$$

By equation 33 :

$$M = W \times k_b.$$

Taking k_b as 21,500 lbs. per square inch :

$$\therefore W = \frac{71{,}000}{21{,}500} = 3{\cdot}3 \text{ inches}^3.$$

A resisting moment of 3·7 cubic inches is given by a channel-iron section with a breadth of flange of $4\frac{3}{4}$ inches and a weight of 27 lbs. per yard, so that this might be selected for the pole. A rather cheaper section would be a T section with a depth of $4\frac{3}{4}$ inches. This has a resisting moment of 3·3 cubic inches and a weight of $22\frac{1}{2}$ lbs. per yard.

If it is intended to run the lines into the building through the support it will be necessary to select a tubular pole. The necessary resisting moment would be given by two iron tubes each of $3\frac{1}{2}$ inches outer diameter, ·2 inch thickness of wall and weighing 40 lbs. per yard of double tube.

In order to see what effect the vertical load on the pole will have the following calculation can be made :—

Taking the span as 130 feet :

	lbs.
Weight of wires $(3 \times \cdot 039 + 1 \times \cdot 0155) \times 3\cdot 9 \times \frac{130}{2}$ . . . . . =	33·5
Additional load $6\cdot 6 \times \cdot 132 \times \frac{130}{2}$ . . . . =	56·5
Weight of cross-arms, insulators, and part of pole above the fixing point =	73
P_v =	163

Taking the case of the channel-iron pole and applying equation 37 (*a*) :

$$k = \frac{P \times e}{W} + \frac{P_v}{F} = \frac{71{,}000}{3\cdot 7} + \frac{163}{2\cdot 65}$$
$$= 19{,}200 + 62$$
$$= 19{,}262 \text{ lbs. per square inch.}$$

That is to say, the vertical force only increases the stress by 62 lbs. per square inch or ·3 per cent., and can, in general, be safely neglected.

EXAMPLE 18.

What load can safely be carried by the tubular iron roof standard shown in Fig. 34 without additional supports ? The outer diameter of the tube is 3 inches and the inner diameter $2\frac{3}{4}$ inches.

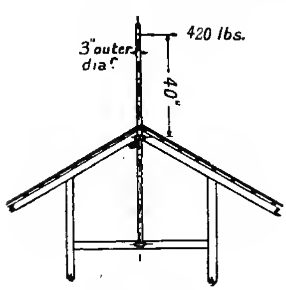


Fig. 34.

The resisting moment of the cross-section of the tube is :

$$W = \frac{\pi}{32} \times \frac{d^4 - d_1^4}{d}$$
$$= \frac{3\cdot 14}{32} \times \frac{3^4 - 2\cdot 75^4}{3} = \cdot 78 \text{ inches}^3,$$

and

$$M = P \times l = W \times k_b.$$

Taking k_b as 21,500 lbs. per square inch :

$$P = \frac{\cdot 78 \times 21{,}500}{40} = 420 \text{ lbs.}$$

If the lines are erected with a maximum stress of 11,500 lbs. per square inch the total cross-section of copper allowable will be $\frac{420}{11{,}500} = \cdot 036$ square inch. If the maximum stress is reduced to 5,750 lbs. per square inch the allowable copper section becomes ·072 square inch.

EXAMPLE 19.

At an angle point in a line a wooden pole of the form shown in Fig. 35 is erected and is subjected to a resultant horizontal force of 930 lbs. and a vertically downward force of 265 lbs. It is required to determine the stress at the dangerous section E and the diameter of strut required. How great must the area of the base plate U of the strut be made if the maximum allowable pressure on the earth is 22 lbs. per square inch ?

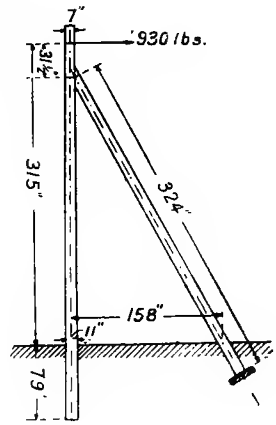


Fig. 35.

The lateral bending force on the strut is, by equation 45 :

$$P_k = \frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right),$$

and

$$e = 31\tfrac{1}{2} \text{ inches}, \; c = 283\tfrac{1}{2} \text{ inches},$$

$$\tan \alpha = \frac{158}{283 \cdot 5} = \cdot 555 \; ; \; \alpha = 29^\circ,$$

$$\sin \alpha = \cdot 485 \; ; \; \cos \alpha \; 1 \cdot 804,$$

or

$$P_k = \frac{930}{\cdot 485}\left(1 + \frac{94 \cdot 5}{567}\right) = 2{,}250 \text{ lbs.}$$

The minimum diameter of strut is, by equation 46 (a),

$$D_1 = \cdot 045 \sqrt[4]{\frac{930 \times 324^2}{\cdot 485}\left(1 + \frac{94 \cdot 5}{567}\right)} = 5 \cdot 5 \text{ inches.}$$

The stress at the dangerous section of the pole (7·5 inches diameter) is, by equation 47 (a),

$$k = \frac{10 \times 930 \times 31 \cdot 5}{7 \cdot 5^3} + \frac{1 \cdot 27}{7 \cdot 5^2}\left\{265 - 930\left(1 + \frac{94 \cdot 5}{567}\right) 1 \cdot 804\right\}$$

$$= 660 \text{ lbs. per square inch.}$$

This is well below the safe working stress of 1,000 lbs. per square inch.

That part of the pole below the strut is subjected to a lateral bending stress due to the sum of the vertical forces. The diameter D required to withstand this stress is found by equation 48 (a) :

$$D = \cdot 045 \sqrt[4]{283 \cdot 5^2 \left\{265 - 930\left(1 + \frac{94 \cdot 5}{567}\right) 1 \cdot 804\right\}}$$

On working this out it is seen that the upward component of the force on the strut far exceeds the vertically downward force P_v, even if the latter is increased by the weight of the pole acting at the centre of gravity and reduced to the length c. No downward force, therefore, exists on the part c of the pole, but, on the contrary, the pole must be specially anchored in the ground to prevent its being lifted.

The force on the strut has been found to be 2,250 lbs., therefore, by equation 28,

$$F = \frac{P}{k_d} = \frac{2{,}250}{22} = 102 \text{ square inches.}$$

The stone or oakwood base-plate should therefore have an area of about 12 inches by 9 inches and a thickness of about 4 inches.

Example 20.

The strut in the last example is to be replaced by a stay-wire attached at the point E and fixed to the wall of a building 16 feet away and acting at right angles to the pole. What size of stay will be required (a) if of round iron rod, (b) if of drawn iron wire rope ? What size of collar must be used on the pole, and what dimensions should the stretching screw (or stay-bow) have ?

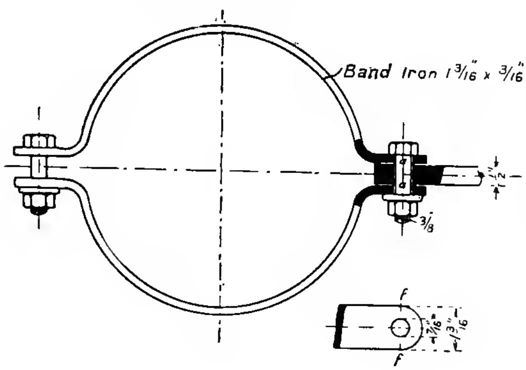


Fig. 36.

The tension in the stay at 90° ($\sin \alpha = 1$) will, by equation 40, be

$$P = 930\left(1 + \frac{94{\cdot}5}{567}\right) = 1{,}090 \text{ lbs.}$$

For case (a) a stress of 14,500 lbs. per square inch can be allowed in the iron rod, so that, by equation 41,

$$d = 1{\cdot}13\sqrt{\frac{1{,}090}{14{,}500}} = {\cdot}31 \text{ inch.}$$

For case (b), using equation 41 (b),

$$F = {\cdot}000035 \times \frac{P}{\sin \alpha}\left(1 + \frac{3}{2}\frac{e}{c}\right) = {\cdot}000035 \times 1{,}090 = {\cdot}038 \text{ square inch.}$$

This area corresponds to two wires each of ·156 inch diameter.

The pole collar can be arranged as in Fig. 36. The closed eye of the stretching screw, inserted in the stay-wire, would be held by one of the collar-bolts and would subject this to a shearing stress at aa. Two cross-sections would, therefore, have to be sheared before breakdown occurs.

$$2 \frac{d^2 \times \pi}{4} \times \cdot 7 \times k_z = P$$

$$2 \times \frac{d^2 \times 3 \cdot 14}{4} \times \cdot 7 \times 14{,}500 = 1{,}090$$

$$d = \sqrt{\frac{4 \times 1{,}090}{2 \times 3 \cdot 14 \times \cdot 7 \times 14{,}500}} = \cdot 263 \text{ inch.}$$

A $\frac{3}{8}$ inch diameter bolt could therefore be used and would allow for the additional stress due to the tightening of the collar. This additional stress should always be allowed for by making the cross-section of bolt 1·2 or 1·3 times that calculated :

The dangerous section in the collar-band occurs at *ff*. The cross-section here, if flat iron $1\frac{3}{16} \times \frac{3}{16}$ inch is used, and the hole is made $\frac{7}{16}$ inch diameter, will be

$$2\left(1\tfrac{3}{16} - \tfrac{7}{16}\right) \times \tfrac{3}{16},$$

and the stress

$$k_z = \frac{1{,}090}{2\left(1\frac{3}{16} - \frac{7}{16}\right)\frac{3}{16}} = 3{,}900 \text{ lbs. per square inch.}$$

When a stay tightener or stretching screw is used the thread diameter of its bolts must be at least equal to that of the stay-rod itself. This has been

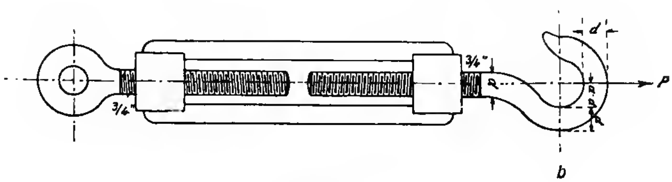


Fig. 37.

found above to be ·31 inch, so that a $\frac{1}{2}$ inch thread, having a diameter of ·39 inch would be required. This would be sufficient if the bolts had plain closed eyes at the ends, but if open hooks are used a greater diameter is necessary. The cross-section b (Fig. 37) is subjected to tension by the force P and also to bending by the moment $P \times a$. The diameter d should, therefore, be made $\frac{3}{4}$ inch and the distance $a = d$. The stress at the section b is then found as

$$k = \frac{P}{F} + \frac{P \times a}{W},$$

where $W = \frac{\pi}{32} d^3$,

$$\therefore k = \frac{1{,}090}{(\frac{3}{4})^2 \times \cdot 785} + \frac{1{,}090 \times \frac{3}{4}}{\frac{3 \cdot 14 \times (\frac{3}{4})^3}{32}} = 22{,}400 \text{ lbs. per square inch.}$$

In order to save material the section at other points than b can be somewhat reduced.

EXAMPLE 21.

A certain long-span line is to be carried on channel-iron masts of the dimensions shown in Fig. 38. The wind pressure acting on the wire (useful load on the masts) amounts to 930 lbs. This force is applied at a mean height of 475 inches (39 feet 7 inches) above the ground. The weight of the lines and additional load on the span of 525 feet is found to be 375 lbs. The design of the masts is to be carried out. The following iron sections will be employed in the calculations :—

I. *Main Stays.*

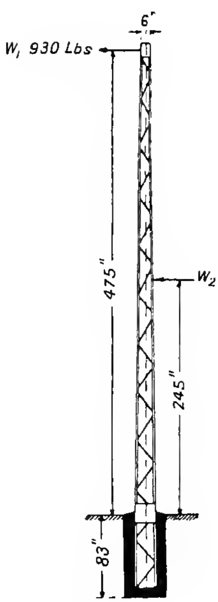


Fig. 38.

Channel-iron of German standard profile No. 10 (= British Standard Section No. 3 approx.) having a weight of $g = 21\frac{1}{2}$ lbs. per yard and a cross-section $f_g = 2{\cdot}1$ square inches.

Thickness of flange $= {\cdot}24$ inch.

The cross-section weakened by a $\frac{1}{2}$-inch rivet amounts to $f_g' = 2{\cdot}1 - (\frac{1}{2} \times {\cdot}24) = 1{\cdot}98$ square inch.

Moment of inertia about the x-axis $= J \; = 5$ (inches)^4.

,, ,, ,, y-axis $= J_y = {\cdot}7$ (inches)^4.

Resisting moment or modulus (of section) about the x-axis $= W_x = 2{\cdot}5$ (inch)^3.

Distance of centre of figure $= \xi = \frac{5}{8}$ inch.

II. *Diagonals.*

Bar iron $1\frac{9}{16} \times \frac{9}{16}$ inch with a cross-section f_d of ${\cdot}88$ square inch and a weight g of 9 lbs. per yard.

Cross-section weakened by a $\frac{1}{2}$ inch rivet to $f_d = {\cdot}88 - {\cdot}5 \times \frac{9}{16} = {\cdot}6$ square inch.

Moment of inertia $J_{\text{min.}} = \dfrac{b^3 h}{12} = \dfrac{(\frac{9}{16})^3 \times 1\frac{9}{16}}{12} = {\cdot}023$ (inch)^4.

III. *Rivets.*

Half inch diameter with a cross-section of ${\cdot}196$ square inch.

I. *Main Stays at the Loaded Section E.*

These are subjected to both vertical and horizontal forces. The former are—weight of mast, fittings, and lines (including additional load); and the latter are—wind pressure on the lines (useful load on the mast) and wind pressure on the mast surface normal to the line direction.

(1) *Vertical Forces.*

Weight of the whole mast (47 feet 6 inches long) = 940 lbs.

		lbs.
,, ,, part of the mast above the ground level $Q = 940 \times \frac{41}{47 \cdot 5}$	=	810
,, ,, line G	=	375
Total weight P_v	=	1,185

(2) *Horizontal Forces.*

	lb.-inches.
Wind pressure on the lines W_1 = 930 lbs. acting with a leverage of 475 inches gives a bending moment M_1 =	440,000
Wind pressure on the mast $W_2 = 41 \times \cdot 33 \times 30$ = 410 lbs. acting at a leverage equal to the height of the centre of figure of the mast (mast centre) and giving a bending moment $M_2 = 410 \times \frac{41 \times 12}{2}$ =	101,000
Total bending moment M_b =	541,000

Distance of centre of figure from the neutral axis (Fig. 39):

$$e = \frac{20}{2} - \xi = 10 - \tfrac{5}{8} = 9 \cdot 375 \text{ ins.}$$

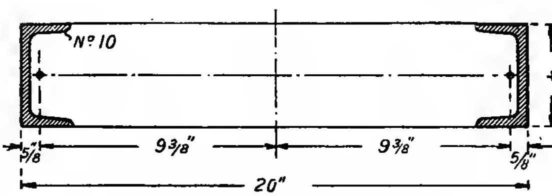


Fig. 39.

These loads produce in the channel or U iron girders tensile or compressive forces equal to

$$P_z = \tfrac{1}{2}\left(\frac{M_b}{e} - P_v\right) = \tfrac{1}{2}\left(\frac{541{,}000}{9 \cdot 375} - 1{,}185\right) = 28{,}400 \text{ lbs.}$$

$$P_d = \tfrac{1}{2}\left(\frac{M_b}{e} + P_v\right) = \tfrac{1}{2}\left(\frac{541{,}000}{9 \cdot 375} + 1{,}185\right) = 29{,}600 \text{ lbs.}$$

The tensile or compressive stress at the section is therefore:

$$k_z = \frac{P_z}{f_g'} = \frac{28{,}400}{1 \cdot 98} = 14{,}400 \text{ lbs. per square inch.}$$

$$k_d = \frac{P_d}{f_g} = \frac{29{,}600}{2 \cdot 1} = 14{,}100 \text{ lbs. per square inch.}$$

The factor of safety against lateral bending with a gross length between diagonals of 51 inches and a free length of 48 inches is

$$s_k = \frac{\pi^2 \times J_{\text{min.}} \times E}{P_d \times l^2} = \frac{3 \cdot 14^2 \times \cdot 7 \times 30 \cdot 7 \times 10^6}{29{,}600 \times 48^2} = 3 \cdot 1.$$

II. *Diagonals.*

The force compressing the lowest diagonal is

$$D = (W_1 + W_2)\,\frac{l_d}{b} = (930 + 410) \times \frac{31}{20} = 2{,}080 \text{ lbs.}$$

and the stress

$$k_d = \frac{D}{f_d} = \frac{2{,}080}{\cdot 88} = 2{,}370 \text{ lbs. per square inch.}$$

The factor of safety against lateral bending is therefore

$$s_k = \frac{\pi^2 \times J_{\text{min.}} \times E}{D \times l_d^2} = \frac{3{\cdot}14^2 \times {\cdot}023 \times 30{\cdot}7 \times 10^6}{2{,}080 \times 31^2} = 3{\cdot}4.$$

III. *Rivets.*

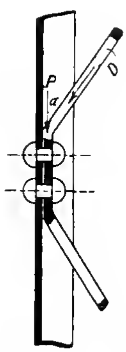


Fig. 40.

The shearing force acting on the rivets (Fig. 40) is

$$P_s = D \times \cos \alpha = 2{,}080 \times \frac{48}{2 \times 31} = 1{,}620 \text{ lbs.}$$

Assuming that the whole force is taken up by one rivet only, the factor of safety against shearing will be

$$s_n = \frac{\frac{2}{3} \times 57{,}000}{1{,}620/{\cdot}193} = 4{\cdot}6,$$

where 57,000 lbs. per square inch is taken as the breaking tensile stress and two-thirds of this as the shearing stress.

IV. *Deflection of the Pole.*

The deflection produced at the end of a free support is *

$$f = \frac{P}{E \times J} \times \frac{l^3}{3}.$$

For the ground level section the distance of the centre of section of the channel iron from the neutral axis has been found to be $l = 9{\cdot}375$ inches. If the width of the top of the mast is 6 inches the distance of the centre of section there will be

$$\frac{6}{2} - \xi = 3 - \tfrac{5}{8} = 2\tfrac{3}{8} \text{ inches.}$$

The average distance of centre of section from the neutral axis is, therefore,

$$\frac{9{\cdot}375 + 2{\cdot}375}{2} = 5{\cdot}87 \text{ inches,} = e_m$$

* See Hütte, Part I., p. 565.

and the mean moment of inertia is

$$J_m = 2\,(J_y + f_g \times e_m^2) = 2\,(\cdot 7 + 2\cdot 1 \times 5\cdot 87^2) = 147 \text{ (inches)}^4.$$

The force effective at the top of the mast is made up of the wind force on the wires together with the wind force on the mast area reduced to the leverage of the top of the mast. The bending moment of this latter force has been worked out above as

$$M_2 = 101{,}000 \text{ lb.-inches.}$$

The effective force at the top of the mast due to this is therefore

$$W_2' = \frac{101{,}000}{475} = 213 \text{ lbs.}$$

The total force at the top is therefore

$$213 + 930 = 1{,}143 \text{ lbs.},$$

and the deflection at the top is

$$f = \frac{1{,}143 \times 475^3}{30\cdot 7 \times 10^6 \times 147 \times 3} = 9 \text{ inches.}$$

Example 22.

A "dead end" or strain mast is to be designed for the line dealt with in example 21. The one-sided line pull amounts to 3,800 lbs. and acts at a point 475 inches (39 feet 7 inches) from the ground. The dimensions are shown in Fig. 41, and the following material will be used :

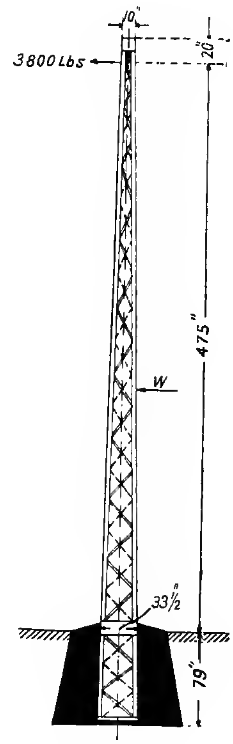


Fig. 41.

I. *Main Stays.*

Angle iron $2\frac{9}{16} \times 2\frac{9}{16} \times \cdot 35$ inches (= British Standard Section No. 7 approx.) having a weight g of $17\frac{1}{2}$ lbs. per yard and a cross-section $f_g = 1\cdot 7$ square inch.

The cross-section where weakened by a $\frac{1}{2}$ inch rivet is

$$f_g' = 1\cdot 7 - (\tfrac{1}{2} \times \cdot 35) = 1\cdot 52 \text{ square inch.}$$

Moment of inertia about the ξ-axis $= J_\xi = 1$ (inch)^4.

,, ,, ,, x-axis $= J_{\text{min.}} = \cdot 42$ (inch)^4.

Distance of the centre of figure from the neutral axis $= \xi = \cdot 76$ inch.

II. *Diagonals.*

Angle iron $1\frac{9}{16} \times 1\frac{9}{16} \times \frac{5}{32}$ inches (= B. S. E. A. 3 approx.) weighing $g = 5$ lbs. per yard and having a cross-section of $f_d = \cdot 48$ square inch. The cross-section where weakened by a $\frac{1}{2}$ inch rivet is $f_d' = \cdot 48 - (\frac{1}{2} \times \frac{5}{32}) = \cdot 4$ square inch. Moment of inertia about the x axis $= J_{\text{min.}} = \cdot 045$ (inch)^4.

III. *Rivets.*

Half inch diameter with a cross-section of ·196 square inch.

Wind Pressure on the Mast in the Direction of the Line Pull.

The front surface of the mast exposed to the wind is made up of :

	square feet
(1) The surface of the angle irons of a length of 495 inches each and a width of $2\frac{9}{16}$ inches $= \dfrac{2 \times 495 \times 2\frac{9}{16}}{12 \times 12}$ . . =	17·6
(2) Surface of the diagonals $= \dfrac{20 \times 26'' \times 1\frac{9}{16}}{12 \times 12}$ . . . =	5·6
(3) 65 per cent. addition for the back surface of the mast, the cross-arms, and the insulators . . . . . . =	15
Total surface . . =	38·2

Allowing 30 lbs. per square foot the wind pressure $= 30 \times 38{\cdot}2 = 1{,}150$ lbs.

This force will act approximately at the centre of figure of the mast area which occurs

$$\frac{33\frac{1}{2} + (2 \times 10)}{33\frac{1}{2} + 10} \times \frac{495}{3} = 203 \text{ inches}$$

above the ground level.

The effective force, reduced to the height at which the line pull occurs is therefore

$$1{,}150 \times \frac{203}{475} = 490 \text{ lbs.}$$

This added to the line pull of 3,800 lbs. gives a total pull of 4,290 lbs.

I. *Stresses in the Angle Irons at the Ground Level E.*

Vertical load :—

		lbs.
Weight of mast above ground Q	$= 1{,}800 \times \dfrac{495}{574} =$	1,555
Weight of lines G	=	375
Total weight	$P_v =$	1,930

This force produces a compressive stress in the angle iron of

$$k_d = \frac{P_v}{4 \times f_g} = \frac{1{,}930}{4 \times 1{\cdot}7} = 285 \text{ lbs. per square inch.}$$

Horizontal load :—

The bending moment due to the line tension and wind pressure is

$$M_b = 4{,}290 \times 475 = 2{,}040{,}000 \text{ lb.-inches.}$$

The distance of the centre of figure from the neutral axis (Fig. 42) is :

$$e = \frac{b}{2} - \xi = \frac{33\cdot5}{2} - \tfrac{3}{4} = 16 \text{ inches.}$$

The bending moment M_b together with the total vertical force P_v produces in each of the four angle irons a tensile or compressive force of

$$P_z = \tfrac{1}{4}\left(\frac{M_b}{e} - P_v\right) = \tfrac{1}{4}\left(\frac{2{,}040{,}000}{16} - 1{,}930\right)$$
$$= 31{,}000 \text{ lbs.}$$

$$P_d = \tfrac{1}{4}\left(\frac{M_b}{e} + P_v\right) = \tfrac{1}{4}\left(\frac{2{,}040{,}000}{16} + 1{,}930\right)$$
$$= 32.000 \text{ lbs.}$$

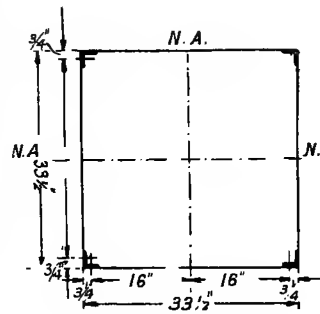


Fig. 42.

These forces produce tensile or compressive stresses in the angle irons at the ground level of

$$k_z = \frac{P_z}{f_g'} = \frac{31{,}000}{1\cdot52} = 20{,}500 \text{ lbs. per square inch.}$$

$$k_d = \frac{P_d}{f_g'} = \frac{32{,}000}{1\cdot52} = 21{,}000 \text{ lbs. per square inch.}$$

With a gross length between diagonals of 55 inches and a free length of 51 inches the factor of safety against lateral bending is

$$s_k = \frac{\pi^2 \times J \times E}{P_d \times l^2} = \frac{3\cdot14^2 \times 1 \times 30\cdot7 \times 10^6}{32{,}000 \times 51^2} = 3\cdot62.$$

II. *Diagonals.*

Since the angle iron mainstays are practically parallel, the greatest tension or compression in a diagonal (Fig. 43) will be

$$D = \frac{1}{2} \times \frac{4{,}290}{\cos\alpha}$$

and

$$\cos\alpha = \frac{31}{\sqrt{31^2 + 23\tfrac{1}{2}^2}}.$$

$$\therefore D = \tfrac{1}{2} \times 4{,}290 \times \frac{\sqrt{31^2 + 23\tfrac{1}{2}^2}}{31}$$
$$= 2{,}680 \text{ lbs.}$$

The stress is then

$$k_d = \frac{D}{fd} = \frac{2{,}680}{\cdot48}$$
$$= 5{,}600 \text{ lbs. per square inch.}$$

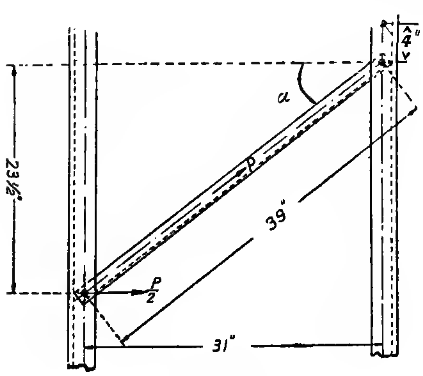


Fig. 43.

$$k_z = \frac{D}{fd'} = \frac{2{,}680}{\cdot 4} = 6{,}700 \text{ lbs. per square inch.}$$

The factor of safety against lateral bending is then

$$S_k = \frac{\pi^2 \times J_{\text{min.}} \times E}{D \times l^2}.$$

$$= \frac{\pi^2 \times \cdot 045 \times 30{\cdot}7 \times 10^6}{2{,}680 \times 39^2} = 3{\cdot}32.$$

III. *Rivets.*

The force acting on the rivets is D. Taking the safe shearing stress $k_s = \frac{2}{3} k_z$, where k_z = safe tensile stress, and the breaking stress under tension as 57,000 lbs. per square inch, the factor of safety for the rivets is

$$s_n = \frac{\frac{2}{3} \times 57{,}000 \times \cdot 196}{2680} = 2{\cdot}8.$$

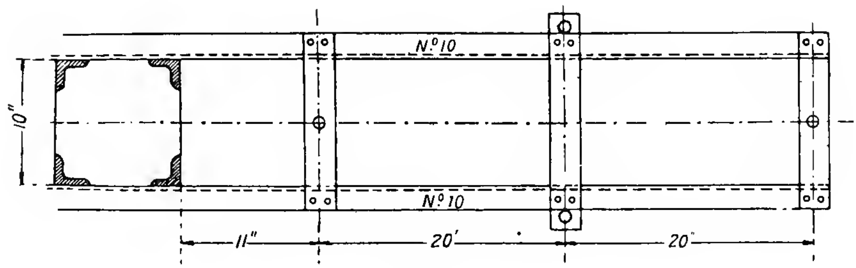


Fig. 44.

IV. *Deflection of Top of Mast.*

The distance between the centre of figure and the neutral axis is 16 inches at the ground level, and at the top of the mast it is

$$\frac{e_k}{2} - \xi = \frac{10}{2} - \tfrac{3}{4} = 4\tfrac{1}{4} \text{ inches.}$$

The mean value is therefore,

$$e_m = \frac{16 + 4\frac{1}{4}}{2} = 10{\cdot}1 \text{ inches.}$$

The mean moment of inertia is therefore

$$J_m = 4\,(J_\xi + f_g \times e_m^2) = 4\,(1 + 1{\cdot}7 \times 10{\cdot}1^2) = 700 \text{ (inch)}^4,$$

and the deflection at the top of the pole will be

$$f = \frac{P \times l^3}{E \times J \times 3} = \frac{4{,}290 \times 475^3}{700 \times 30{\cdot}7 \times 10^6 \times 3} = 7 \text{ inches.}$$

EXAMPLE 23.

The mast of example 22 is fitted with cross-arms as shown in Fig. 44 consisting of two channel irons (German standard section No. 10 = B. S. C. 3 approx.) connected by bar iron $2\frac{3}{8}$ inches × ·4 inch section. The one-sided pull P is 1,240 lbs. What stress are the channel irons subjected to ?

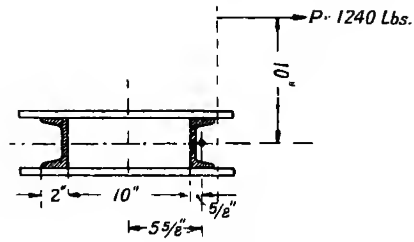


Fig. 44A.

No. 10 channel iron has a cross-section of 2·1 square inches and a moment of inertia J_y = ·7 (inch)^4. The distance of the centre of figure from the neutral axis is $\frac{5}{8}$ inch and the resisting moment (or modulus of section) W_x is 2·5 (inch)^3.

The force P produces a tensile or compressive force in the two channel irons of

$$k' = \frac{P \times l}{e}.$$

From Figs. 44 and 44A it can be seen that l = 31 inches and $e = 11\frac{1}{4}$ inches.

$$\therefore k' = \frac{1{,}240 \times 31}{11\frac{1}{4}}.$$

In addition to this the channel irons are also subjected to a twisting couple due to the pull P of the wires on the insulators at a leverage of 10 inches.

This produces a bending moment in the channel irons with the leverage l = 31 inches and equal to :

$$M_b = \frac{M_d \times l}{e} = \frac{1{,}240 \times 10 \times 31}{11\frac{1}{4}}.$$

The total stress on one channel iron is therefore

$$k_b = \frac{k'}{f} + \frac{M_b}{W_x} = \frac{1{,}240 \times 31}{11\frac{1}{4} \times 2{\cdot}1} + \frac{1{,}240 \times 10 \times 31}{11\frac{1}{4} \times 2{\cdot}5}$$
$$= 15{,}200 \text{ lbs. per square inch.}$$

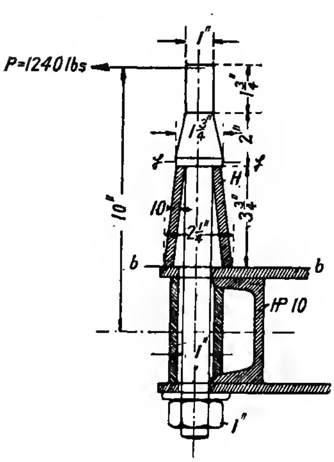


Fig. 45.

EXAMPLE 24.

The force of 1,240 lbs. used in the last example acts on an insulator whose pin support is shown in Fig. 45. What stress is set up in the material ?

The pin is subjected to bending stress at the section y—y and the amount of this stress is

$$k_b = \frac{M}{W} = \frac{P \times l \times 32}{\pi \times d^3} = \frac{1{,}240 \times 3\frac{3}{4} \times 32}{\pi \times (1\frac{3}{4})^3}$$
$$= 8{,}800 \text{ lbs. per square inch.}$$

At the section b—b the collar H is subjected to compression and the pin itself to tension.

The compression at b—b is

$$H = \frac{P\,(l - 2 + \cdot 4)}{\text{Distance of centre of figure.}}$$

The distance of the centre of figure from the neutral axis (central axis of pin):

$$e = \frac{4}{3 \times \pi} \times \frac{R^3 - r^3}{R^2 - r^2} = \frac{4}{3 \times 3{\cdot}14} \times \frac{(1\frac{1}{8})^3 - (\cdot 72)^3}{(1\frac{1}{8})^2 - (\cdot 72)^2} = \cdot 6 \text{ inch.}$$

$$\therefore H = \frac{1{,}240 \times 7\frac{1}{2}}{\cdot 6} = 15{,}500 \text{ lbs.}$$

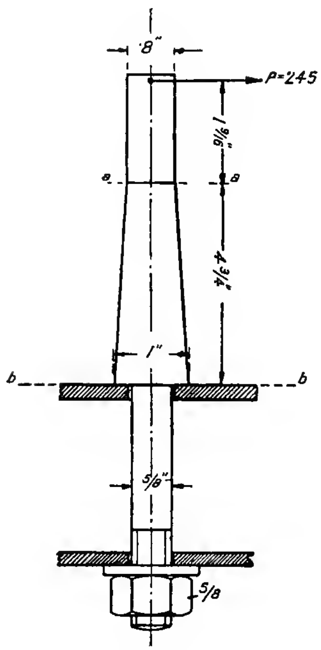


Fig. 46.

$$k_d = \frac{H}{F_H} = \frac{15{,}500}{\frac{1}{2}\,\pi\,(1\frac{1}{8}^2 - \cdot 72^2)}$$

The compressive stress in the collar is then
= 13.200 lbs. per square inch.

The tensile stress in the pin is

$$k_z' = \frac{H}{F_b} = \frac{15{,}500}{1^2 \times \cdot 785}$$
$$= 20{,}000 \text{ lbs. per square inch.}$$

and in the thread (·84 inch minimum diameter) the stress is 28,000 lbs. per square inch.

This would be too high for a wrought-iron bolt, so that the bolt must either be made of steel or its dimensions must be increased.

Example 25.

The stresses in the insulator pin shown in Fig. 46 are to be investigated, the force on the insulator being 245 lbs.

Bending moment at a—a :—

$$M = 245 \times 1\tfrac{9}{16} = 383 \text{ lb.-inches.}$$

$$k = \frac{M}{W} = \frac{383 \times 32}{\pi \times (\cdot 8)^3} = 7{,}600.$$

Pressure on b—b :—

$$H = \frac{245 \times 4\frac{3}{4}}{e}$$

and

$$e = \frac{4}{3 \times 3{\cdot}14} \times \frac{\cdot 5^3 - \cdot 31^3}{\cdot 5^2 - \cdot 31^2} = \cdot 26 \text{ inch.}$$

$$\therefore H = \frac{245 \times 4\frac{3}{4}}{\cdot 26} = 4{,}500 \text{ lbs.}$$

The compressive stress at b—b is, therefore,

$$k_d = \frac{H}{F} = \frac{4{,}500}{\cdot 24} = 18{,}800 \text{ lbs. per square inch.}$$

$$(F = \tfrac{1}{2}\,\pi\,(\cdot 5^2 - \cdot 31^2) = \cdot 24 \text{ square inch.})$$

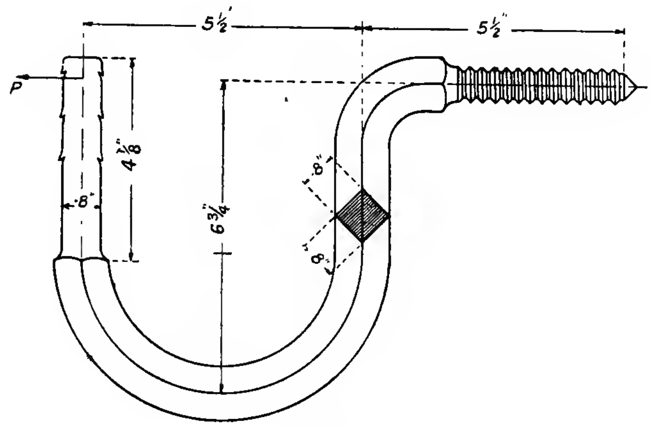


Fig. 47.

The tensile stress in the $\frac{5}{8}$ inch bolt, with a minimum diameter of ·51 inch and a cross-sectional area of ·203 square inch, is

$$k = \frac{4{,}500}{\cdot 203} = 22{,}200 \text{ lbs. per square inch.}$$

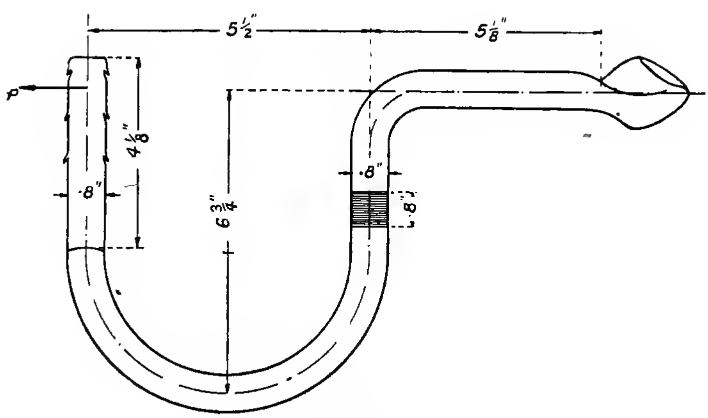


Fig. 48.

Example 26.

Bent iron brackets for insulators can be carried out in square-sectioned iron either as shown in Fig. 47 or as in Fig. 48. The resisting moment (modulus of section) W of Fig. 47 is $\cdot 1178 \times h^3$ and of Fig. 48 it is $\frac{h^3}{6}$.

What maximum horizontal force can the brackets stand without the stress exceeding 21,500 lbs. per square inch ?

The bracket is subjected to a bending moment $P \times l$, so that for Fig. 47 :—

$$P = \frac{k \times W}{l} = \frac{21{,}500 \times \cdot 8^3 \times \cdot 1178}{6\frac{3}{4}} = 190 \text{ lbs.}$$

For Fig. 48 :

$$P = \frac{k \times W}{l} = \frac{21{,}500 \times \cdot 8^3}{6\frac{3}{4} \times 6} = 272 \text{ lbs.}$$

The arrangement of Fig. 48 will therefore permit of a considerable saving in material.

Example 27.

Design of a cross-arm of the form shown in Fig. 49. Channel iron of German Standard section No. 10 (= B. S. C. 3 approx.). Cross-section = 2·1 square inch.

Moment of inertia $J_x = 4{\cdot}95$ (inch)^4.

„ „ $J_y = \cdot 71$ (inch)^4.

Distance of centre of figure $= \xi = \frac{5}{8}$ inch.

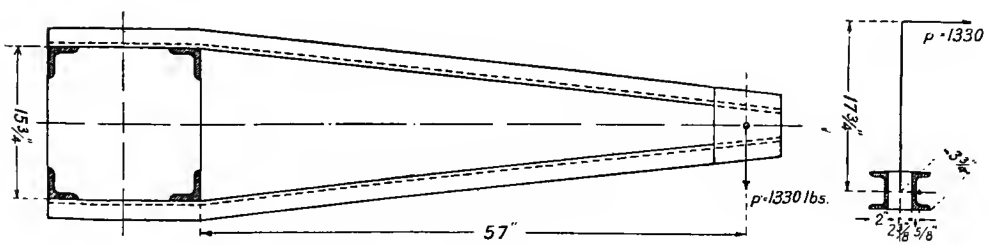


Fig. 49.

The force of 1,330 lbs. tends to twist the system with a leverage of $17\frac{3}{4}$ inches :

$$M_p = W_p \times k_d.$$

The polar resisting moment W_p is equal to the polar moment of inertia J_p divided by the greatest distance of any point of the section from the centre of section s. This distance is $3\frac{3}{4}$ inches.

The polar moment of inertia of a symmetrical cross-section is equal to the sum of two equatorial moments of inertia taken with reference to two axes through the centre of figure and at right angles to one another.

In this case :

$$J_x = 2 \times 4{\cdot}95 \quad . \quad . \quad = 9{\cdot}9 \text{ (inch)}^4.$$

$$J_y = 2\left\{{\cdot}71 + 2{\cdot}1 \times (1\tfrac{13}{16})^2\right\} = 15{\cdot}22 \text{ (inch)}^4.$$

$$\text{Sum} = 25{\cdot}12$$

$$\therefore W_p = \frac{25{\cdot}12}{3\frac{3}{4}} = 6{\cdot}7 \text{ (inch)}^3.$$

and $$k_d = \frac{1{,}330 \times 17\frac{3}{4}}{6{\cdot}7} = 3{,}500 \text{ lbs. per square inch.}$$

Security against lateral bending :—

The force P on one of the channel iron beams :

$$P = \frac{1{,}330 \times 57}{15\frac{3}{4}} = 4{,}800 \text{ lbs.}$$

Factor of safety :

$$\frac{\pi^2 \times J_{\text{min.}} \times E}{P \times l^2} = \frac{3{\cdot}14^2 \times {\cdot}71 \times 30{\cdot}7 \times 10^6}{4{,}800 \times 57^2} = 13{\cdot}8.$$

The pin used with this cross-arm would be fitted with a hexagon head above the bedding face for use whilst the nut at the bottom is being tightened. Smaller pins are, for the sake of cheapness, often simply provided with two parallel flats for this purpose.

5. STABILITY OF POLES AND MASTS.

Poles and masts used for line supports must be embedded to a depth depending on the height of the mast, and the soil must then be well punned or rammed down, and in the case of soft ground additional special precautions must be taken. General rules cannot be laid down, and each case must be considered on its merits.

The foundation arrangements depend chiefly on the kind of mast used and on the length of span. Wooden poles on straight stretches, considering the comparatively short spans for which they are used, generally need no special precautions in good firm ground.

In sandy or loose soil, or, in the case of corner poles, even in firm ground, a special construction is often necessary in order to ensure sufficient stability under the most unfavourable conditions.

Iron masts, used as strain or terminal masts at dead ends, and so subjected to heavy line tensions, or masts subjected to great wind pressure, are often mounted on concrete foundations, which give the necessary stability and also protect the bottom of the mast from rust.

The allowable compressive stress (stress at the edges of the base) depends on the nature of the ground. For rock foundations pressures of 100 to 200 lbs. per square inch are allowable. For reliable building foundation (stony ground, gravel and coarse sand, dry layers of fine sand, loam and clay) values of 55 to 85 lbs. per square inch should not be exceeded. Still smaller values must be kept to for unsafe ground (wet clay, loam, and sand). Drifted sand, bog-land, turf and made ground give very poor support, and the pressure should not exceed 15 lbs. per square inch.

The size of the foundations depends on the forces acting on them, the nature of the ground, and the degree of stability desired. The degree of stability must be chosen to match the factor of safety on the rest of the line construction. Mere supporting (or intermediate) masts are cut as fine as possible in order to economise cost, as they are normally only required to withstand the wind pressure on the line acting at right angles to the direction of the line. This force also is the chief one to be considered in designing the foundation. Such masts are not expected to withstand the additional forces thrown on them when a breakage of the lines occurs on one side. If the masts are made of channel iron they will generally be able to give sufficiently in the direction of the line to take up the additional load without permanent damage to themselves, especially as this deflection reduces the tension decidedly. For larger line cross-sections and for long spans such elastic structures do not usually offer any advantage. The cost of providing intermediate masts of sufficient strength to withstand the heavy

additional load due to wire breakage would be prohibitive. It is usual, therefore, to design these masts simply to withstand the wind pressure, and in case of a breakage in the wires on one side the masts are subjected to excessive stresses and more or less damaged. If, however, the fixing in the ground is of such a nature that the masts are free to set themselves at a moderate slant when the excessive sideway force occurs, this will relieve the tension without damaging the mast itself. The deviation from the vertical will, in any case, be small, so that little risk of the mast falling exists. The labour and expense of righting such slanting masts is decidedly less than that of replacing or straightening bent iron masts.

Symmetrical Ground Pressure.

The sum of the weights of the foundations, the mast and fittings, and half the wire (including additional load) in the two neighbouring spans constitutes the vertical load acting on the mast foundation and producing a symmetrical compressive force on the ground.

If σ_s = the compressive stress,

ΣG = sum of all vertical forces,

F = area of foundation surface,

then
$$\sigma_s = \frac{\Sigma G}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad 55$$

Unsymmetrical Ground Pressure.

If a force Q (Fig. 50) acts at a point, which is not the centre point, on a surface of breadth b and length of 1 inch, an unsymmetrical distribution of the stress on the ground occurs. The compressive stress on one half will be greater the further the point of action is from the centre point.

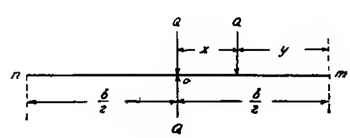


Fig. 50.

If two equal and opposite forces Q are assumed to be applied at the centre point O and in a direction parallel to the original force Q, no alteration in the conditions will result. The force acting downwards at O produces a uniformly distributed compressive stress σ_1 on the ground. The remaining two forces constitute a couple with the twisting moment $Q \times x$ which produces a bending stress σ_2. In this case a compressive stress $+\sigma_m$ is produced at m whilst a tensile stress $-\sigma_n$ is set up at n. The following equations, therefore, hold :

$$\sigma_1 = \frac{Q}{F} = \frac{Q}{1 \times b},$$

$$Q \times x = \sigma_2 \times W.$$

For the rectangle $1 \times b$:

$$W = \frac{1 \times b^2}{6},$$

$$\therefore \sigma_2 = \frac{6 \times Q \times x}{1 \times b^2}.$$

At the points m and n respectively the following forces exist on the ground:

$$\sigma_m = \frac{Q}{b}\left(1 + \frac{6 \times x}{b}\right),$$

$$\sigma_n = \frac{Q}{b}\left(1 - \frac{6 \times x}{b}\right).$$

If $\sigma_n = 0$:

$$0 = \frac{Q}{b}\left(1 - \frac{6 \times x}{b}\right)$$

$$\therefore x = \frac{b}{6} \qquad . \quad . \quad . \quad . \quad 56$$

For this case:

$$\sigma_m = \frac{2\,Q}{b} \qquad . \quad . \quad . \quad . \quad . \quad . \quad 57$$

For $x > \frac{b}{6}$ σ_n becomes negative, and for $x < \frac{b}{6}$ it becomes positive.

If the stress at n is 0:

$$y = \frac{b}{2} - x = \frac{b}{2} - \frac{b}{6} = \frac{b}{3}, \text{ or } b = 3\,y.$$

$$\therefore \quad \sigma_m = \frac{2\,Q}{3\,y} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 58$$

If the compressed surface is of rectangular form with a depth $= b$ then

$$\sigma_m = \frac{2\,Q}{3\,yb} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 59$$

Lateral Earth Pressure (Active and Passive Earth Pressure).

If a mass of earth is sifted on to a horizontal surface it will form a conical mound whose side forms a definite angle ϕ (the "angle of repose") with the horizontal, depending on the nature of soil used (Fig. 51). If this cone is cut anywhere at an angle steeper than its natural angle ϕ the soil at this point will no longer be in stable equilibrium and must be supported. The force acting on such a support is called the active (effective) earth pressure.

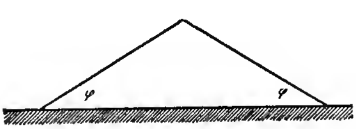


Fig. 51.

A passive (static) force also exists when a supporting wall is pushed outwards against the earth behind it by outside forces, as, for instance, in the case of a mast foundation forced against the

surrounding earth. The passive earth pressure is decidedly greater than the active earth pressure.

For hard punned soil or virgin soil the angle up to which no sliding takes place is considerably greater than for new soft ground. Under certain conditions, however, such as a rising of the surface water, etc., the cohesion of the earth can be seriously reduced or even abolished.

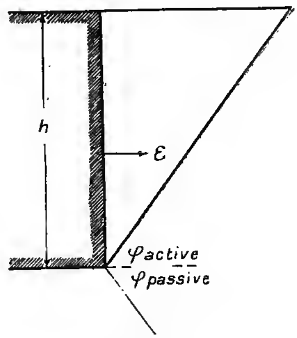


Fig. 52.

The direction of the earth pressure depends on the form and inclination of the wall surface and the friction coefficient between wall and earth. In order to be on the safe side loose earth and no appreciable friction between foundation and earth should be assumed, *i.e.*, the earth pressure should be taken to be at right angles to the wall surface. On these assumptions and for the simple case shown in Fig. 52, viz., wall surface vertical and base horizontal, the active earth pressure is given by the expression

$$E_a = \frac{1}{2} \times \gamma \times h^2 \times \tan^2\left(45^\circ - \frac{\phi}{2}\right) \quad . \quad . \quad . \quad . \quad 60$$

The passive earth pressure acts on the wall at an angle ϕ below the normal to the wall surface :

$$E_p = \frac{1}{2} \times \gamma \times h^2 \tan^2\left(45^\circ + \frac{\phi}{2}\right) \quad . \quad . \quad . \quad . \quad 61$$

If the specific earth pressure is σ :

$$E = \sigma \times 1 \times \frac{h}{2},$$

so that

$$\sigma_{\text{active}} = \gamma \times h \times \tan^2\left(45^\circ - \frac{\phi}{2}\right) \quad . \quad 62$$

and

$$\sigma_{\text{passive}} = \gamma \times h \times \tan^2\left(45^\circ + \frac{\phi}{2}\right) \quad . \quad . \quad . \quad 63$$

In these equations :

E = earth pressure in lbs. on a strip of wall 1 inch wide ;
σ = specific earth pressure in lbs. per square inch ;
γ = weight of the soil filling in lbs. per cubic inch ;
h = height of the mass of earth in inches ;
ϕ = natural angle of slope.

The following table (17) gives average values for the natural angle of slope ϕ and for the weight of a cubic inch for various kinds of soil :

TABLE 17.

Nature of Soil.	Natural Angle of Slope $= \phi$.	Weight in lbs. per cubic inch $= \gamma$.	$\text{Tan}^2\left(45^\circ - \frac{\phi}{2}\right)$.	$\text{Tan}^2\left(45^\circ + \frac{\phi}{2}\right)$.
Dry loam . .	43°	·055	·189	4·972
Wet loam . . .	25°	·074	·406	2·465
Dry clay . .	45°	·059	·171	5·808
Wet clay . . .	25°	·074	·406	2·465
Wet gravel . .	30°	·068	·333	2·992
Shingle (damp) . .	40°	·063	·217	4·579

INFLUENCE OF THE FORCES BELOW THE GROUND LEVEL.*

When a pole fixed in the ground is subjected to a bending moment forces are set up in the ground as indicated by the force diagram in Fig. 53. When a state of equilibrium exists two conditions will be complied with—(1) the sum of all the forces must be zero, and (2) the turning moment due to the internal forces must be equal to the externally applied moment.

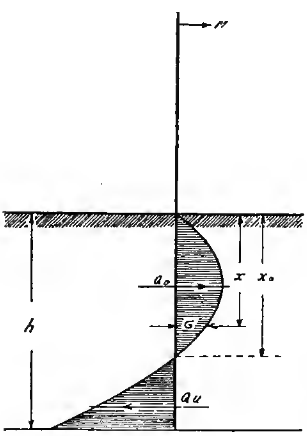


Fig. 53.

The first condition is stated by the equation

$$Q_o = Q_u,$$

or

$$\int_o^h \sigma \times dx = 0 \quad . \quad . \quad . \quad . \quad . \quad (\text{I.})$$

Since the resistance of the material to contraction under the action of the compressing forces varies in proportion to its depth, *i.e.*, the extension coefficients β are inversely proportional to the depths, the following relation holds :

$$\beta_1 : \beta_2 = x_2 : x_1 \quad . \quad . \quad (\text{II.})$$

If Δ represents the strain produced then :

$$\text{for } x_1 \quad . \quad . \quad . \quad . \quad \Delta_1 = \beta_1 \times \sigma_1$$

and

$$\text{for } x_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad \Delta_2 = \beta_2 \times \sigma_2$$

or

$$\Delta_1 : \Delta_2 = \beta_1 \, \sigma_1 : \beta_2 \, \sigma_2 \quad . \quad . \quad . \quad (\text{III.})$$

* See Ullmann, "Beton and Eisen," 1909, p. 18.

If the pole is assumed to be absolutely rigid the following relation holds good, as shown in Fig. 54 :

$$\Delta_1 : \Delta_2 = (x_0 - x_1) : (x_0 - x_2) \quad . \quad . \quad \text{(IV.)}$$

From equations (III.) and (IV.) :

$$\beta_1 \sigma_1 : \beta_2 \sigma_2 = x_2 \sigma_1 : x_1 \sigma_2$$

Combining the proportions :

$$\frac{x_0 - x_1}{x_0 - x_2} = \frac{x_2 \sigma_1}{x_1 \sigma_2} \quad . \quad . \quad . \quad \text{(V.)}$$

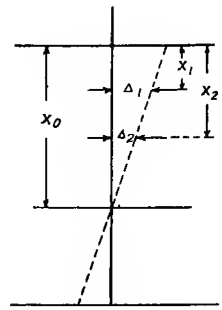


Fig. 54.

If σ is substituted for σ_1, x_1 will become x, and if σ_b is substituted for σ_2, x_2 will become h, so that

$$\frac{x_0 - x}{x_0 - h} = \frac{h \times \sigma}{\sigma_b \times x},$$

or

$$\sigma = \frac{\sigma_b}{(x_0 - h)h} \times (x_0 - x)x \quad . \quad . \quad . \quad . \quad \text{(VI.)}$$

Inserting this value for σ in equation (I.) :

$$\frac{\sigma_b}{(x_0 - h)h} \int_0^h (x_0 \times x - x^2)dx = 0 = \frac{\sigma_b}{(x_0 - h)h} \left(\frac{x_0 h^2}{2} - \frac{h^3}{3} \right)$$

from which

$$x_0 = \frac{2}{3} h \quad . \quad . \quad \text{(VII.)} \quad . \quad . \quad 64$$

Inserting this value for x_0 in equation (VI.) :

$$\sigma = \frac{\sigma_b}{h_2} (2\,h - 3\,x)x \quad . \quad \text{(VIa.)}$$

This is the equation to a parabola whose vertex (or $\sigma_{\text{max.}}$) occurs at the abscissa x_1 (Fig. 55),

where
$$\frac{d\sigma}{dx} = 0$$

or

$$k\,(2\,h - 6\,x) = 0,$$

from which

$$x_1 = \frac{1}{3} h \quad . \quad . \quad \text{(VIII.)}$$

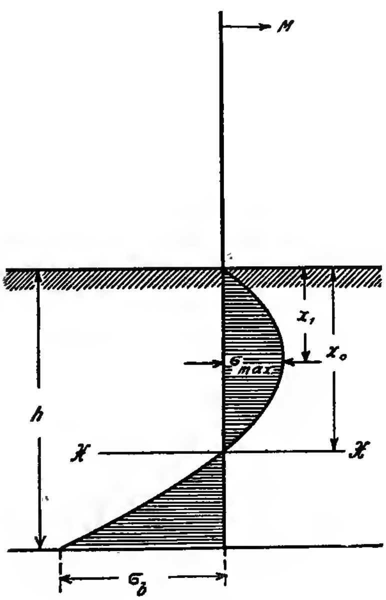


Fig. 55.

The internal moment of forces M_i, which has to be equal to the external moment M, is given by the sum

$$\int_0^{-\frac{2}{3}h} \sigma . x . dx + \int_0^{+\frac{1}{3}h} \sigma . x . dx.$$

Working out equation (VI.) for the $x - x$ axis :

$$\sigma = \frac{\sigma}{h^2} (2\,h + 3\,x)\,x,$$

$$\therefore\ M_i = \frac{\sigma_b}{h^2} \left[\int_{-\frac{2}{3}h}^{0} (2\,h + 3\,x)\,x^2 . dx + \int_{+\frac{1}{3}h}^{0} (2\,h + 3\,x)\,x^2 . dx \right] = \frac{\sigma_b \times h^2}{12} \quad \text{(IX.)}$$

If b is the breadth of the pole (assumed constant), then

$$M_i = \frac{M}{b}$$

or

$$\sigma_b = \frac{12\,M}{b \times h^2} \quad . \quad . \quad . \quad . \quad . \qquad 65$$

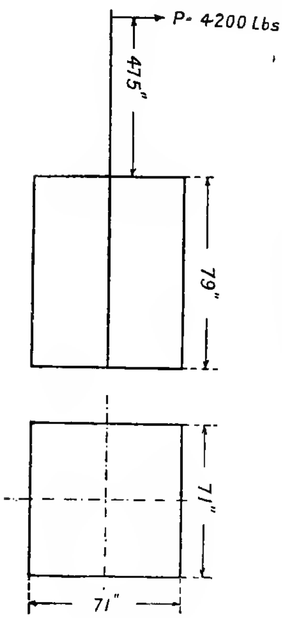


Fig. 56.

EXAMPLE 28.

The strain mast dealt with in example 22 is to be fixed in the ground by means of a concrete foundation (Fig. 56). What size of foundation is required (*a*) if the lateral earth pressure is counted upon, and (*b*) if the lateral earth pressure is left out of account, the maximum ground pressure being limited to 57 lbs. per square inch ?

(*a*) With lateral earth pressure allowed for :—

Weight of mast . . .	G_M	=	1,830 lbs.
Weight of lines with additional load . . .	G_z	=	375 ,,
Maximum horizontal force acting normally to one of the foundation sides .	P	=	4,200 ,,
Height at which P is applied	L	=	475 inches.

Assuming a foundation block 71 × 71 × 79 inches (*i.e.*, 227 cubic feet of material),

Total weight, at 137 lbs. per cubic foot, = 137 × 227 = 31,000 lbs.

The combined weight of mast, lines, and foundation block produces a symmetrical ground pressure (equation 55) of

$$\sigma_s = \frac{1{,}830 + 375 + 31{,}000}{71 \times 71} = 6{\cdot}7 \text{ lbs. per square inch.}$$

By equation 56 when

$$\sigma_n = 0: \ x = \frac{b}{6} = \frac{71}{6} = 11{\cdot}8.$$

By Fig. 57 it will be seen that the maximum allowable additional stress due to bending moment is $57 - 6{\cdot}7 = 50{\cdot}3$.

The average bending stress over the whole surface is therefore $\frac{50{\cdot}3}{2}$, and the total allowable bending moment is

$$M = 71 \times 71 \times 11{\cdot}8 \times \frac{50{\cdot}3}{2}$$
$$= 1{,}490{,}000 \text{ lb.-inches.}$$

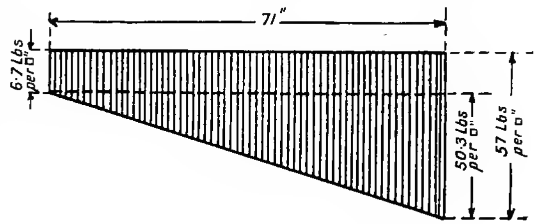


Fig. 57.

The bending moment actually applied is

$$M_F = 4{,}200 \left(475 + \frac{2}{3} \times 79\right)$$
$$= 2{,}220{,}000 \text{ lb.-inches.}$$

The difference between these two values must be taken up by the surrounding soil. This amounts to

$$M = 2{,}220{,}000 - 1{,}490{,}000$$
$$= 730{,}000 \text{ lb.-inches.}$$

This, by equation 65, corresponds to a stress

$$\sigma_b = \frac{12\,M}{b\,h^2} = \frac{12 \times 730{,}000}{71 \times 79} = 20 \text{ lbs. per square inch.}$$

The counteracting passive earth pressure, by equation 63, is

$$\sigma_p = \gamma\, h \tan^2\left(45^\circ + \frac{\phi}{2}\right)$$

Taking $\gamma = {\cdot}063$ lbs. per cubic inch and $\tan^2\left(45^\circ + \frac{\phi}{2}\right) = 4{\cdot}58$ for damp shingle (see Table 17),

$$\sigma_p = {\cdot}063 \times 79 \times 4{\cdot}58 = 22{\cdot}7 \text{ lbs. per square inch.}$$

As this value exceeds the actual stress σ_b of 20 lbs. per square inch the foundation dimensions are correct.

(*b*) Leaving the lateral earth pressure out of account :—

Assuming a size of foundation block (Fig. 58) of 95 × 95 × 79 inches (410 cubic feet), the weight would be

$$137 \times 410 = 56{,}000 \text{ lbs.}$$

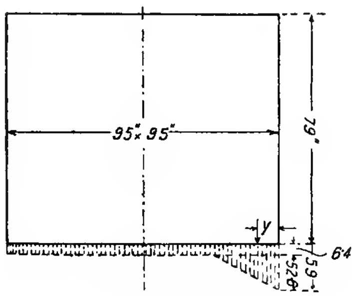


Fig. 58.

The moment on the base of the foundation block is

$$M_F = 4{,}200 \times (475 + 79)$$
$$= 2{,}330{,}000 \text{ lb.-inches.}$$

This moment must be equal to the moment of the internal forces, or

$$2{,}330{,}000 = (1{,}830 + 375 + 56{,}000) \times x,$$

or

$$x = 39{\cdot}7 \text{ inches}$$

and

$$y = \frac{b}{2} - x = 47{\cdot}5 - 39{\cdot}7 = 7{\cdot}8 \text{ inches.}$$

Therefore the additional floor pressure, by equation 59, is

$$\sigma_m = \frac{2\ (1{,}830 + 375 + 56{,}000)}{3 \times 7{\cdot}8 \times 95} = 52{\cdot}6 \text{ lbs. per square inch,}$$

and the symmetrical floor pressure, by equation 55, is

$$\sigma_s = \frac{1{,}830 + 375 + 56{,}000}{95 \times 95} = 6{\cdot}4 \text{ lbs. per square inch.}$$

∴ The total pressure $= \sigma_s + \sigma_m = 52{\cdot}6 + 6{\cdot}4 = 59$ lbs. per square inch.

The weight of this foundation is (56,000 — 31,000) = 25,000 lbs. greater than that calculated under (*a*) taking into account the effect of lateral earth pressure. This additional weight, allowing 15*s*. per cubic yard of concrete, would cost

$$\frac{25{,}000}{137 \times 27} \times \frac{15}{20} = £5 \text{ about.}$$

In the above calculation a square base was assumed and a rectangular vertical section. By changing the shape the mass of concrete required can be reduced without diminishing the security, as will be seen from the following considerations :—

The line tension on the strain mast of a straight line acts in the direction of the line. At right angles to the line direction the mast is only subjected to wind pressure, which is small compared with the line tension. Consequently the foundation base should be of rectangular shape if the floor pressure is to be alike in both directions.

(c) Assuming that the foundation block is given the shape shown in Fig. 59, to calculate the stresses, taking into account the lateral earth pressure :—

$$\text{Weight of foundation} = \frac{(59 \times 59 \times 59 + 59 \times 83 \times 20)137}{1{,}728} = 24{,}200 \text{ lbs.}$$

$$\text{Sum of vertical forces} = (1{,}830 + 375 + 24{,}200) = 26{,}405 \text{ lbs.}$$

$$\sigma_s = \frac{26{,}405}{83 \times 59} = 5{\cdot}4 \text{ lbs. per square inch.}$$

The bending moment acting on the foundation has been found above in (a) to be 2,220,000 lb.-inches.

The moment which can be taken up by the base without allowing the floor pressure to exceed 57 lbs. per square inch is

$$83 \times 59 \times \frac{83}{6} \times \frac{(57 - 5{\cdot}4)}{2}$$
$$= 1{,}750{,}000 \text{ lb.-inches.}$$

The remainder, viz., 2,220,000 — 1,750,000 = 470,000 lb.-inches, must be taken up by sideway earth pressure. This corresponds to a pressure at the edge of

$$\sigma_b = \frac{12 \times 470{,}000}{59 \times 79^2}$$
$$= 15{\cdot}4 \text{ lbs. per square inch.}$$

The passive earth pressure is

$$\sigma_p = {\cdot}063 \times 79 \times 4{\cdot}58$$
$$= 22{\cdot}7 \text{ lbs. per square inch,}$$

which is on the safe side.

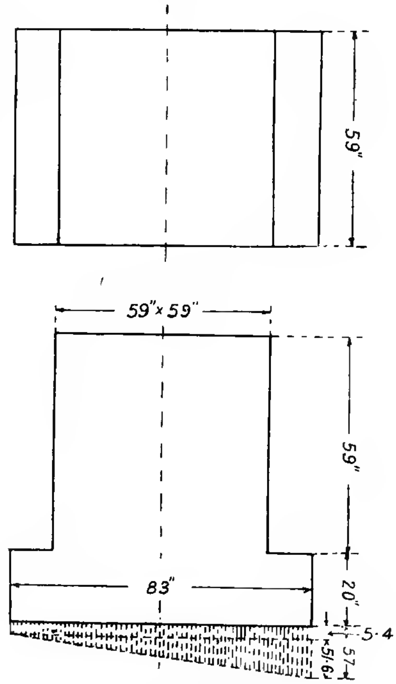


Fig. 59.

The saving effected as compared with arrangement (a) is

$$\frac{31{,}000 - 24{,}200}{137 \times 27} \times \frac{15}{20} = £1\ 8s.$$

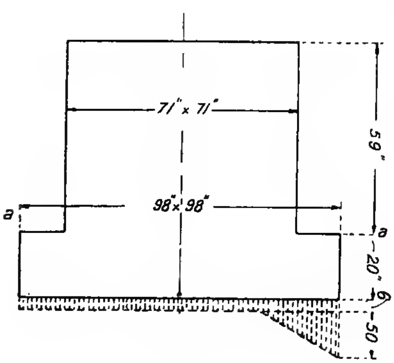


Fig. 60.

(d) Square base with vertical section as shown in Fig. 60—lateral earth pressure not taken into account, but the effect of the weight of earth lying on sections a—a to be taken into account :—

Weight of foundation :

$$\frac{(98 \times 98 \times 20 + 71 \times 71 \times 59)137}{1{,}728}$$
$$= 38{,}000 \text{ lbs.}$$

Weight of earth over a—a :

$$(98^2 - 71^2)59 \times \cdot063 = 16{,}600 \text{ lbs.}$$

$$2{,}330{,}000 = (38{,}000 + 16{,}600 + 1{,}830 + 375) \times x = 56{,}805 \times x.$$

$$x = 41 \text{ inches.}$$

and $$y = \frac{b}{2} - x = 49 - 41\cdot2 = 7\cdot8 \text{ inches.}$$

$$\sigma_m = \frac{\frac{2}{3} \times 56{,}805}{7\cdot8 \times 98} = 50 \text{ lbs. per square inch,}$$

and the symmetrical ground pressure is

$$\sigma_s = \frac{56{,}805}{98 \times 98} = 6 \text{ lbs. per square inch.}$$

$\therefore$ Total pressure :

$$50 + 6 = 56 \text{ lbs. per square inch.}$$

Saving as compared with arrangement (b) :

$$\frac{56{,}000 - 38{,}000}{137 \times 27} \times \frac{15}{20} = £3\ 13s.$$

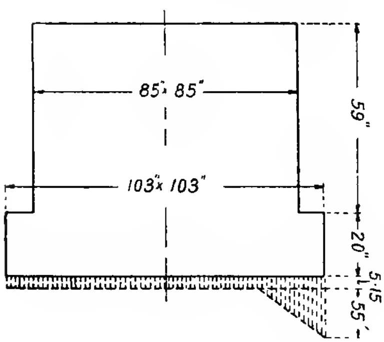


Fig. 61.

(e) Square base with vertical section as shown in Fig. 61, the lateral earth pressure and the weight of earth lying over the foundation projecting ledge not to be taken into account :—

Weight of foundation block :

$$\frac{(85^2 \times 59 + 103^2 \times 20) \times 137}{1{,}728}$$
$$= 51{,}000 \text{ lbs.}$$

$$2{,}330{,}000 = (51{,}000 + 1{,}830 + 375) \times x = 53{,}205 \times x.$$

$$x = 45\cdot1 \text{ inches.}$$

$$y = 6\cdot4 \text{ inches.}$$

$$\sigma_m = \frac{\frac{2}{3} \times 53{,}205}{6\cdot4 \times 103} = 55 \text{ lbs. per square inch.}$$

Symmetrical floor pressure :

$$\sigma_s = \frac{53{,}205}{103 \times 103} = 5\cdot15 \text{ lbs. per square inch.}$$

Total pressure

$$= 55 + 5\cdot15 = 60\cdot15 \text{ lbs. per square inch.}$$

Additional cost as compared with (d) :

$$\frac{51{,}000 - 38{,}000}{137 \times 27} \times \frac{15}{20} = £2\ 13s.$$

(*f*) Rectangular base (110 × 83 inches) with vertical section as shown in Fig. 62. The lateral earth pressure and the weight of the earth lying over the projecting ledge not to be taken into account :—

Weight of foundation :

$$\frac{(83^2 \times 55 + 110 \times 83 \times 23\tfrac{3}{4}) \times 137}{1{,}728} = 47{,}300 \text{ lbs.}$$

$$2{,}330{,}000 = (47{,}300 + 1{,}830 + 375)\,x = 49{,}505 \times x,$$

$$x = 46{\cdot}8 \text{ inches}, \; y = 8{\cdot}2 \text{ inches},$$

$$\sigma_m = \frac{\tfrac{2}{3} \times 49{,}505}{8{\cdot}2 \times 83} = 48{\cdot}5 \text{ lbs. per square inch},$$

$$\sigma_s = \frac{49{,}505}{110 \times 83} = 5{\cdot}4 \text{ lbs. per square inch.}$$

Total pressure

$$= 48{\cdot}5 + 5{\cdot}4 = 53{\cdot}9 \text{ lbs. per square inch.}$$

Saving as compared with (*e*) :

$$\frac{51{,}000 - 47{,}300}{137 \times 27} \times \frac{15}{20} = 15s.$$

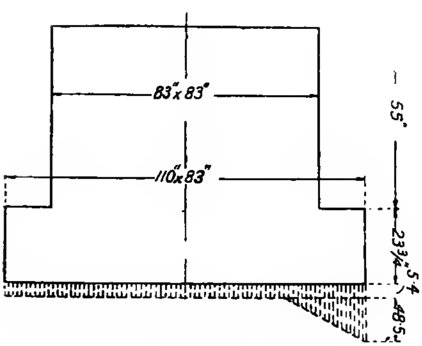


Fig. 62.

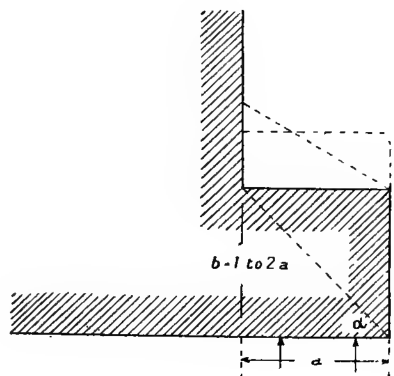


Fig. 63.

In dimensioning foundation blocks in this way it must be remembered that the pressure on the surface *a* subjects the section *b* (Fig. 63) to a bending moment. The stress set up by this should not exceed 57 lbs. per square inch. For floor pressures of 40 to 70 lbs. per square inch it is advisable to make $\frac{a}{b} = \frac{1}{1}$ (*i.e.*, angle $\alpha = 45°$) or $= \frac{3}{4}$. With higher earth pressures the ratio should be kept to $\frac{1}{2}$, or a foundation having the shape of a truncated regular pyramid, as shown in Fig. 64, should be selected.

The production of this form of foundation with slanting sides is somewhat more difficult, as the concrete cannot easily be forced into the corners unless the mould is gradually built up as the concrete is poured in and rammed home.

(*g*) Foundation as shown in Fig. 64, consisting of a truncated regular pyramid with square base :

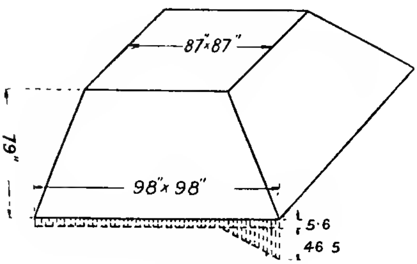


Fig. 64.

The general expression for the cubic content of a truncated pyramid is

$$\frac{1}{3} h(F + f + \sqrt{F f}),$$

where F and f are the bottom and top areas and h is the height.

The weight in this case is, therefore,

$$\frac{1}{3} \times 79(98^2 + 87^2 + \sqrt{98^2 \times 87^2}) \times \frac{137}{1{,}728}$$
$$= 54{,}000 \text{ lbs.}$$

$$2{,}330{,}000 = (54{,}000 + 1{,}830 + 375) \times x = 56{,}205\, x.$$
$$x = 41{\cdot}2 \text{ inches.}$$
$$y = 7{\cdot}8 \text{ inches.}$$
$$\sigma_m = \frac{\frac{2}{3} \times 54{,}000}{7{\cdot}8 \times 98} = 46{\cdot}5 \text{ lbs. per square inch.}$$
$$\sigma_s = \frac{54{,}000}{98 \times 98} = 5{\cdot}6 \text{ lbs. per square inch.}$$

Total pressure :

$$46{\cdot}5 + 5{\cdot}6 = 52{\cdot}1 \text{ lbs. per square inch.}$$

Example 29.

To determine the depth to which the pole used in example 16 must be let into the ground.

Here the height above the ground $= l =$ 23 feet (276 inches) and at this height a force P of 575 lbs. acts. The diameter of pole at the ground level was found to be 11·6 inches, so that the diameter in the ground may be taken as 12 inches. Taking the effective width of compressed surface as $\cdot 7 \times D$ it will be $\cdot 7 \times 12 = 8{\cdot}4$ inches in this case. The maximum pressure on the surrounding earth is not to exceed 43 lbs. per square inch.

By equation 65 :

$$\sigma = \frac{12 \times M}{b \times h^2}.$$

Assuming the depth h of pole underground to be 6 feet 6 inches (78 inches), then, since

$$x_0 = \frac{2}{3} h \text{ and } M = P\,(l + x_0),$$
$$M = 575\left(276 + \frac{2}{3} \times 78\right),$$

and

$$\sigma = \frac{12 \times 575\left(276 + \frac{2}{3} \times 78\right)}{\cdot 7 \times 12 \times 78^2} = 43{\cdot}5 \text{ lbs. per square inch,}$$

as required.

EXAMPLE 30.

The supporting mast of a long-span overhead line is to be fixed in the ground without concrete foundation. In order to obtain the necessary stability the foot is arranged as shown in Fig. 65. The total tension acting at the top of the pole, a height of 42 feet above the ground, is 1,100 lbs. The holding down force on the mast foot is made up of the weight of the earth resting on the rectangular

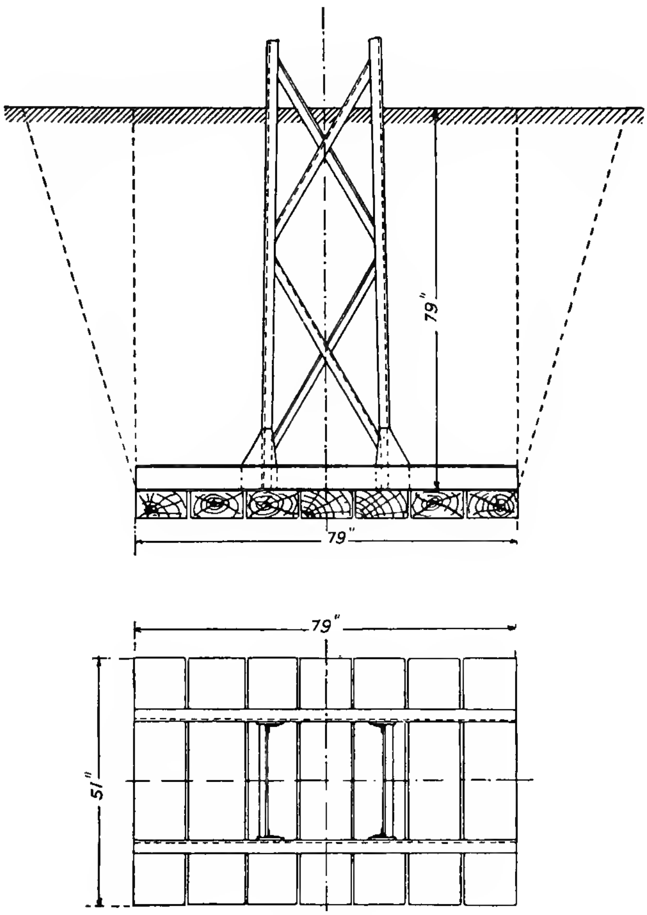


Fig. 65.

surface 79 × 51 inches, together with the weight of the earth forming the two side wedges. In order to be on the safe side only the " active " earth pressure will be considered, the " passive " pressure due to friction being neglected.

The weight of the mast and lines is 1,800 lbs.

Assuming dry loam (see Table 17) the weight per cubic inch $\gamma = \cdot 055$ lbs. and $\tan^2\left(45^\circ - \frac{\phi}{2}\right) = \cdot 189$.

Weight of earth:

$$79 \times 79 \times 51 \times \cdot 055 + 2 \times \frac{1}{2} \times \cdot 055 \times 79^2 \times 51 \times \cdot 189$$

$$= 17{,}400 + 3{,}300 = 20{,}700 \text{ lbs.}$$

Moment of forces acting on the base plate:

$$1{,}100 \times (42 \times 12 + 79) = 640{,}000 \text{ lb.-inches.}$$
$$640{,}000 = (1{,}800 + 20{,}700)\, x = 22{,}500 \times x.$$
$$x = 28 \cdot 3 \text{ inches,}$$

and

$$y = \frac{b}{2} - x = 39 \cdot 5 - 28 \cdot 3 = 11 \cdot 2 \text{ inches,}$$

and the floor pressure is

$$\sigma_m = \frac{\frac{2}{3}\,(1{,}800 + 20{,}700)}{11 \cdot 2 \times 51} = 26 \quad \text{lbs. per square inch.}$$

$$\sigma_s = \frac{1{,}800 + 20{,}700}{79 \times 51} = 5 \cdot 6 \quad \text{,,} \quad \text{,,}$$

Total pressure .. .. $= 31 \cdot 6$,, ,,

Since dry loam can stand 60 to 85 lbs. per square inch safely the dimensions of this foot could be reduced if desired.

6. THE FORCES SET UP IN THE FOUNDATION BLOCK.

THE forces acting within the body of the foundation block are indicated by Fig. 66.

The stresses σ_e at the top and bottom are alike and oppositely directed. The change of direction occurs at the centre of the block. The distributed forces indicated by the two shaded triangles may be replaced by a pair of forces Q acting at the centres of figure of the triangles, and, therefore, with a leverage of $\frac{2}{3}h'$. The couple thus set up counterbalances the moment acting externally on the mast :

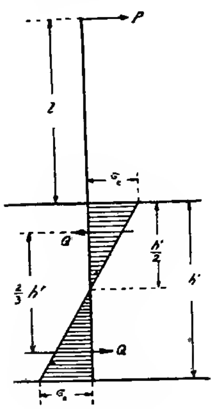


Fig. 66.

$$\therefore \quad M = \frac{2}{3} h' Q ;$$

and

$$\text{since } Q = \frac{1}{2} \sigma_e \frac{h'}{2}$$

$$M = \frac{\sigma_e \times h'^2}{6}$$

and

$$\sigma_e = \frac{6\,M}{h'^2} .$$

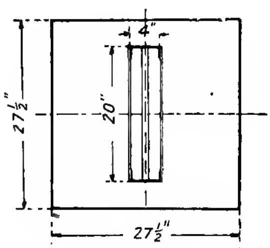


Fig. 67.

If b is the breadth of the supporting surface and h' its height then

$$\sigma_e = \frac{6\,M}{b \times h'^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad 66$$

EXAMPLE 31.

The mast dealt with in example 21 is to be embedded in a concrete foundation block of the form shown in Fig. 67. What is the maximum stress at the edge of the concrete ?

The moment of the forces acting is

$$M = P\left(l + \frac{h'}{2}\right) = 930\left(475 + \frac{79}{2}\right) = 480{,}000 \text{ lb.-inches.}$$

$$\therefore \quad \sigma_e = \frac{6\,M}{b \times h'^2} = \frac{6 \times 480{,}000}{4 \times 79^2} = 115 \text{ lbs. per square inch.}$$

This stress is far below that allowable for concrete of even poor composition.

For foundations for poles a poor quality of concrete is allowable—such as is obtained for instance with a composition made up in the ratio 1 : 5 : 10—as even this withstands a maximum crushing stress of about 1,700 lbs. per square inch.

If the mast is put into the ground without any concrete foundation the conditions would be as follows :—

The bottom of the mast would rest on a sheet-iron base-plate say 27 × 7 inches. The weight of the mast is 1,000 lbs. and that of the line with additional load is 880 lbs.

The symmetrical earth pressure is therefore

$$\sigma = \frac{1{,}000 + 880}{27 \times 7} = 10 \text{ lbs. per square inch.}$$

If a maximum pressure of, say, 70 lbs. per square inch is allowed, then the moment which can be taken up by pressure on the base is

$$M_E = 27 \times 7 \times \frac{70 - 10}{2} \times \frac{27}{6} = 25{,}500 \text{ lb.-inches.}$$

The moment effective two-thirds of the way down the embedded portion of the mast is

$$M = 930 \left(475 + \frac{2}{3} \times 79\right) = 490{,}000 \text{ lb.-inches.}$$

The moment to be taken up by means of lateral earth pressure is therefore

$$M_r = 490{,}000 - 25{,}500 = 464{,}500 \text{ lb.-inches.}$$

The maximum (edge) pressure is, therefore,

$$\sigma = \frac{12 \times M_r}{b\,h^2} = \frac{12 \times 464{,}500}{4 \times 79^2} = 223 \text{ lbs. per square inch.}$$

The counteracting passive earth pressure is

$$\sigma_p = \gamma \times h \times \tan^2\left(45^\circ + \frac{\phi}{2}\right),$$

and, taking $\tan^2\left(45^\circ + \frac{\phi}{2}\right)$ as 4·56 and γ as ·063 for dry soil,

$$\sigma_p = {\cdot}063 \times 79 \times 4{\cdot}56 = 22{\cdot}7 \text{ lbs. per square inch.}$$

The mast is therefore unable to support itself with this arrangement unless an enlarged foundation is provided. The surface over which the pressure is distributed could be increased by fitting strong iron sheets or girders or by using old railway sleepers.

EXAMPLE 32.

The condition of the strain mast of example 22 with the concrete foundation of example 28 is to be investigated as to the stress set up in the concrete.

A concrete mixture in the ratio 1 : 4 : 8 will be assumed, having a crushing stress of 2,000 lbs. per square inch. The safe working stress will be taken as one-fifth of this = 400 lbs. per square inch.

The dimensions of the foundation are shown in Fig. 68. The compression surface is that offered by the four angle iron stays each $2\frac{9}{16} \times 2\frac{9}{16}$ inches, the remaining members not being taken into account.

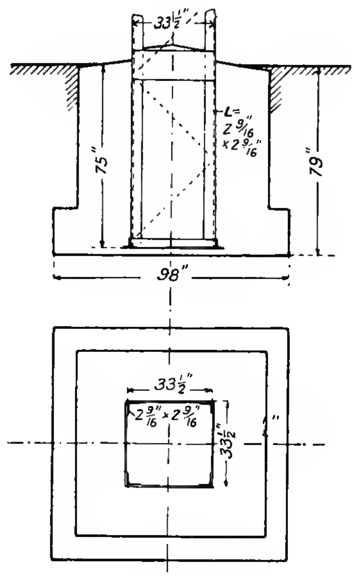


Fig. 68.

The moment acting on the foundation :

$$= M = P\left(l + \frac{h'}{2}\right)$$

$$= 4{,}200\left(475 + \frac{75}{2}\right)$$

$$= 2{,}150{,}000 \text{ lb.-inches.}$$

$$\therefore \quad \sigma_c = \frac{6\,M}{b \times h'^2} = \frac{6 \times 2{,}150{,}000}{4 \times 2\frac{9}{16} \times 75^2} = 225 \text{ lbs. per square inch.}$$

The hollow space enclosed within the four angle irons must be well rammed down if the support of the inner surfaces of the angle irons at the back is to be taken into account as in the above. Owing to the difficulty of handling the tools inside the mast this point is often neglected.

7. FIXING THE POLES IN THE GROUND.

The fixing of the poles by means of the soil thrown up in excavating the hole is the simplest and cheapest plan. The earth is filled in in layers 6 or 8 inches deep and then punned or rammed hard with a 20—25 lb. punner. Virgin soil is more cohesive than soil which has been disturbed and replaced. The mast should, therefore, whenever possible, be placed against one side of the excavation. Greater security is attained if a fifth to a quarter of a cubic yard of broken stone is added when filling in. This stone should be placed in two layers (Fig. 69) about the pole.

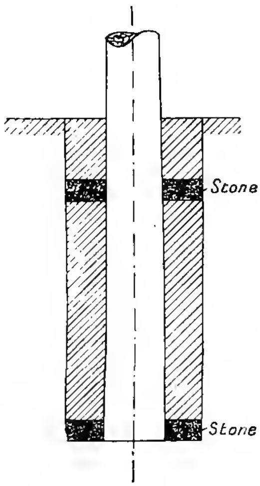


Fig. 69.

The depth to which a wooden pole should be let into the ground can be taken as about one-fifth of the clear length above ground. Poles placed on hillocks should be let in a little deeper, whilst in rocky ground the depth can be reduced to one-seventh of the clear length.

Struts can be fixed in the ground either as shown in Fig. 70 or as in Fig. 71. In the first arrangement the strut beds against a stone or oakwood base having an area of about 10 × 12 inches and a thickness of 4 or 5 inches. This base should be buried to a depth of 3 or 4 feet. A smaller depth is sufficient if the arrangement of Fig. 71 is adopted. Here the pressure of the strut is taken up by a horizontal notched wooden block, which is prevented from shifting by driving in a square peg 30 to 40 inches long. The strut and its base are held together by pins.

The angle α between the strut and the pole should not be less than 25° or greater than 50°. With smaller angles the pressure on the strut would be too great, whilst with more than 50° the length of the strut becomes excessive.

If, owing to the surroundings, the strut has to be placed at a steep angle, or if the ground is poor or the pole stands in surface water, it is advisable to anchor the mast in addition as shown in Fig. 70, especially if the point of attachment of the strut lies low. A wire stay is attached just above the ground level and held at the other end by a buried stone or iron anchor plate. Stay wires can be fixed in the earth by means of stones or anchor plates as in the case of struts (Fig. 72). An anchor plate can consist of a piece of sheet iron about $\frac{1}{4}$ inch thick and 16 × 16 inches in area to which angle iron strips have been riveted diagonally as shown in Fig. 73. In the middle an eye bolt is attached to which the iron stay rod or wire rope is fixed. The anchor plate should be buried 4 or 5 feet. When the

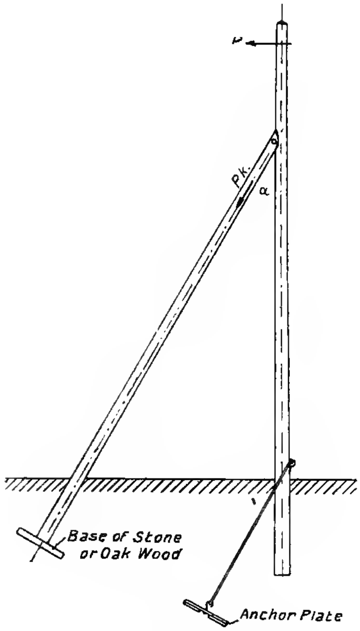


Fig. 70.

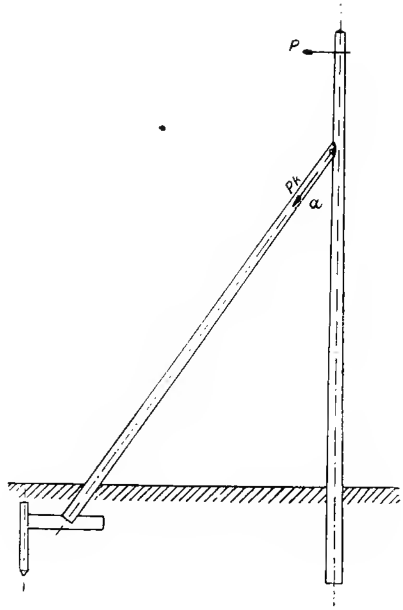


Fig. 71.

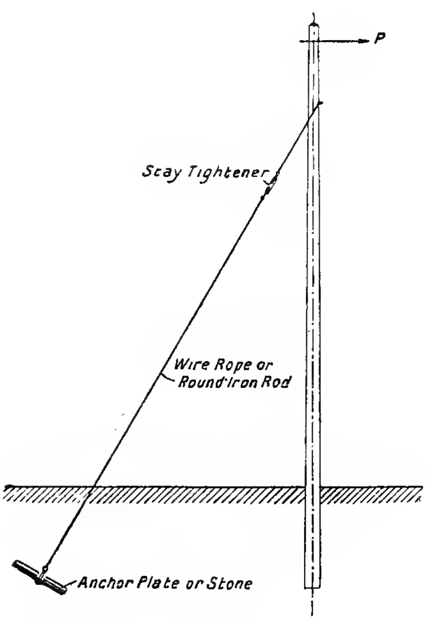


Fig. 72.

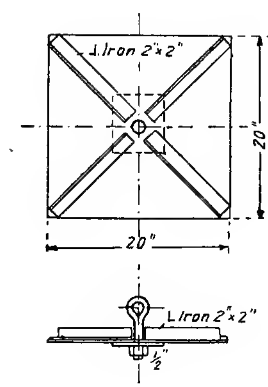


Fig. 73.

tension on the pole is not very great it is often sufficient to attach the stay wire to a peg about 6 inches in diameter and 3 or 4 feet long driven in slantingly so as to form an angle of about 90° with the stay wire as shown in Fig. 74. The stay wire is prevented from slipping on the peg by means of a notch.

Stays should not be fixed to trees, as the motion produced in the latter by the wind is conveyed to the pole and is liable to cause the wires to swing into contact.

According to the latest rules of the Board of Trade and of the V. D. E. stay wires must either be earthed or else fitted with reliable strain insulators at a point out of reach from the ground. An insulator suitable for such a purpose is shown in Fig. 75. These are supplied capable of withstanding pulls up to one ton. The insulation material is moulded round a steel core. This insulator is sometimes arranged with one end piece forming the shank of a stay-tightener or stretching-screw. Another form consists of a ribbed insulator gripped between two clamps in such a way that the porcelain is only subjected to compressive stress. The breaking load in this case is about 13,000 lbs.

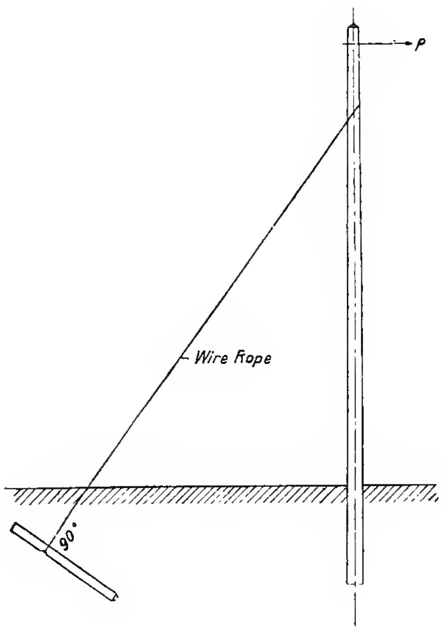


Fig. 74.

Double masts of A form (Fig. 76) are let into the earth to a depth of $5\frac{1}{2}$ or $6\frac{1}{2}$ feet, and the foot is stiffened by the addition of cross-pieces of split logs or old railway sleepers.

In order to increase the surface available for taking up the pressure at right angles to the line direction additional cross-arms are fitted. Cheap stone is used to weight the mast foot. The ends of the mast feet rest on flat stones or tree-stump sections in order to keep the floor pressure within allowable values.

Double masts of H form are similarly fixed. It is not advisable to mount wooden masts or poles in concrete as the alternations of the wet and dry states of the wood cause cracks to appear between the pole and the concrete. These become filled with water and, in case of frost, may lead to the disruption of the foundation.

Fig. 75.

The foundationing of iron masts must be arranged to suit the soil, the allowable tension, and the factor of safety desired. In quicksand or bog land, and in districts generally in which flooding through rising surface water may be

expected, the cost of concrete foundations cannot be avoided. Strain masts, angle masts, and towers must always have concrete foundations.

Iron structures which are let into the ground without concrete should be given a coating of hot tar, which protects the iron from oxidation for a long period. Even better results are attained by a rust-proof coating made of a solution of coal tar in heavy coal tar oil.

Masts which are anchored in the ground by means of concrete foundations either have feet running right through or else are fixed by means of foundation bolts to previously completed concrete foundations (see Figs. 110 and 111). The latter method is appreciably dearer and so is only adopted when it is essential to finish the foundation work before the delivery of the masts or when the supports take the form of double masts with three or four feet (Fig. 175) or are complete structures, as in Figs. 112 and 113.

The shape and size of the foundation block depends on the nature of the soil, the factor of safety desired, and the allowable tensile and compressive stresses. The types most commonly adopted have already been dealt with in the numerical examples of this section. Whatever type is used it is important to keep the base of the foundation at a depth which will be permanently free from frost (at least one yard).

The concrete must be so finished off at the top that no chance of water collecting and remaining on it exists. The arrangement where the concrete touches the iron should, therefore, be as indicated on the left of Fig. 77.

Permission to erect a mast on private property is often difficult to obtain. The owner will give leave more readily if the dimensions of the mast and its foundations are kept small. It may, consequently, be advisable to keep the top of the foundations well below the ground level, so that the land may be worked (ploughed, etc.) right up to the mast foot (see Fig. 78).

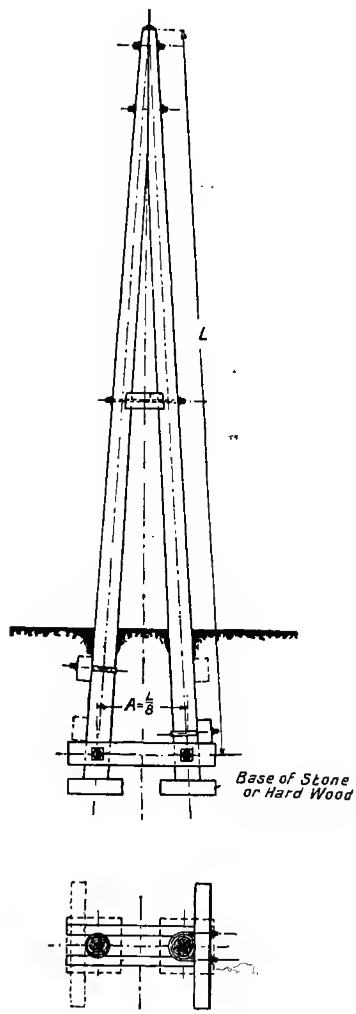


Fig. 76.

The portion of the mast underground but above the concrete foundation block should be protected by a thin covering of reinforced concrete or by a sheet metal cover. The iron reinforcement of this reinforced concrete cover can either consist of narrow-mesh wire netting or of round iron rods bent into U-shape and hung round the foot-plate (Fig. 78).

Many attempts have been made to replace the expensive concrete foundations by some cheaper substitute. These attempts take one of two forms :

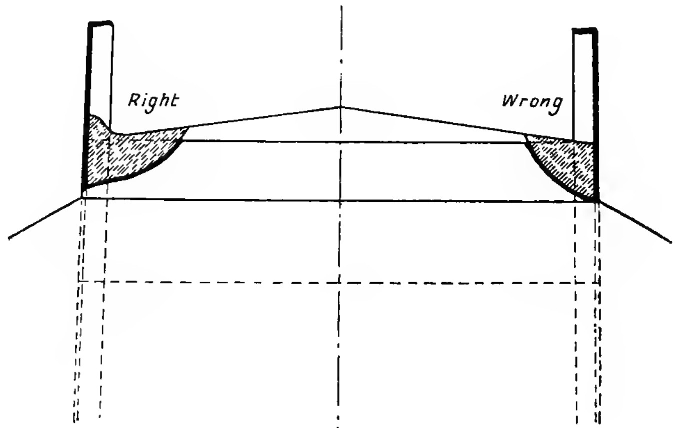


Fig. 77.

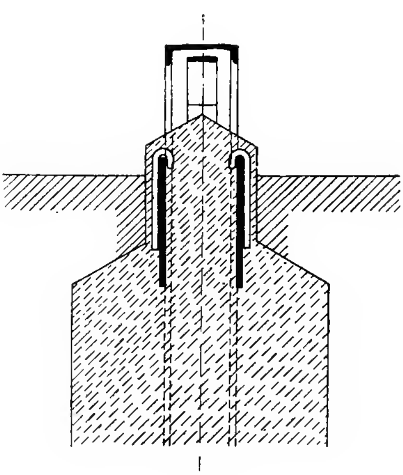


Fig. 78.

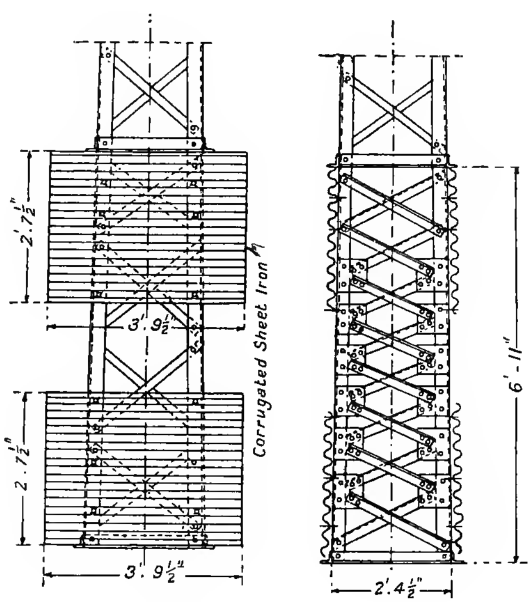


Fig. 79.

either the surface of the mast foot is increased so that the force on the mast is taken up laterally by a greater volume of earth, or the base of the mast is extended so that the weight of earth lying over this base may take up the force in the same

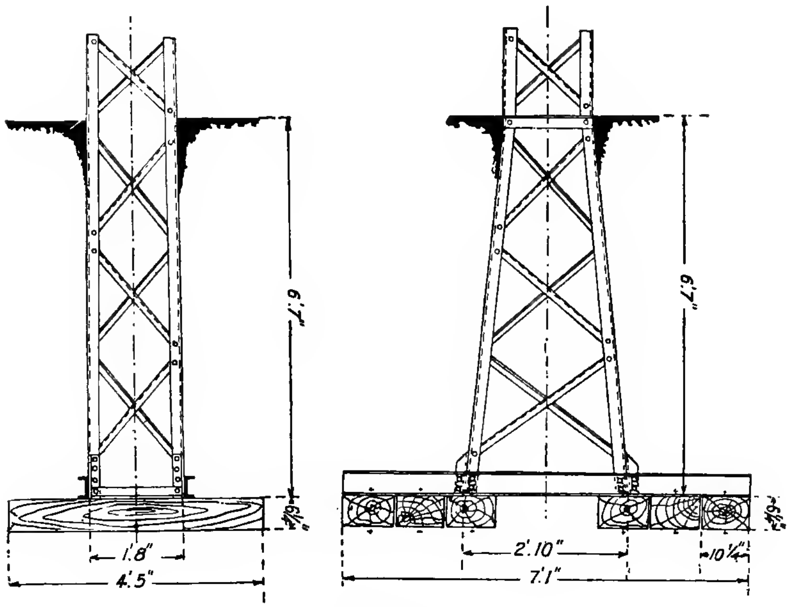


Fig. 80.

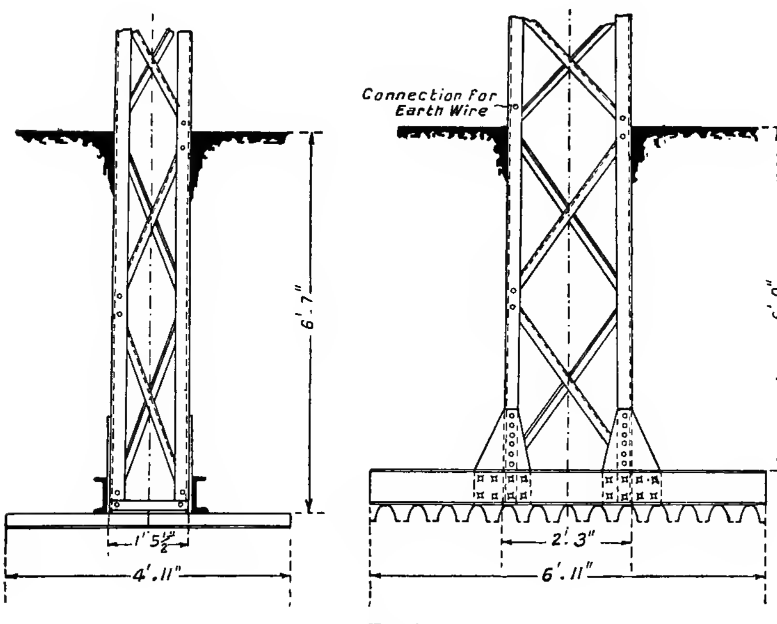


Fig. 81.

way that a mass of concrete does. The first method only effects a small saving, as the additions required to the mast foot in the form of strong corrugated iron are large and expensive.

When the forces on the mast are not large the required addition to the compressed surface can be obtained by the use of old railway sleepers in place of the corrugated iron. In these cases the uppermost sleepers should only be fixed after the earth below has been rammed hard.

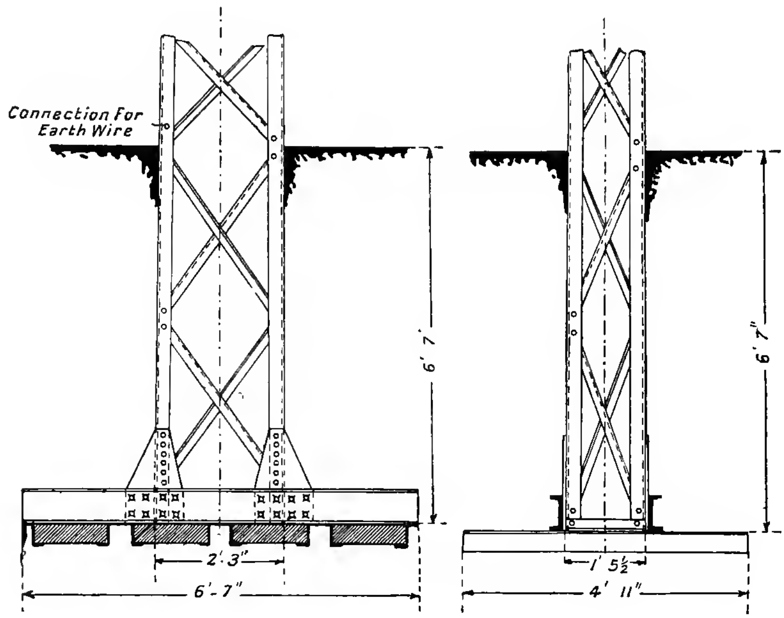


Fig. 82.

Fig. 79 shows a construction using corrugated sheet or sheet iron stiffened with angle iron, the angle iron also serving to increase the strength of the mast foot. Figs. 80 and 81 show methods of increasing the area of the mast base. Instead of wooden beams some arrangements employ Z-iron clamps in which reinforced concrete beams can be placed (Fig. 82).

8. CONCRETE AND CEMENT FOUNDATION WORK.

THE cement used for concrete work must be fresh and of the best quality, and must be quick or slow setting, according to the nature of the work. The former is only required in the presence of water, whilst for all other work slow-setting cement is preferable.

A cement is called slow if it does not begin to set in less than one hour after mixing. The actual hardening of the cement begins after the setting, and proceeds more quickly with slow-setting cement than with the quick-setting variety ; a greater degree of strength is also attained by the former in a shorter time. It is, therefore, not at all necessary to employ quick-setting cement for work that is required for use quickly.

Whilst hardening is proceeding the work should be shielded from sun and wind, which tend to deprive the cement too quickly of the water which is necessary for hardening.

In cold weather both the setting and the hardening processes are delayed, and a longer time should be allowed to elapse before loading the work. If cement work has to be carried out in frosty weather care should be taken to use as little water as possible and to mix thoroughly. If warm water is used the rate of setting can be increased.

Cement mixed with sand alone forms cement mortar, whilst cement with sand, broken stone, and gravel forms concrete. According to the nature of the work the proportion of the different constituents is varied ; for greater strength the proportion of cement must be increased.

The materials used must be selected with care, as their quality has great influence on the resulting concrete.

The sand (quartz sand) must be sharp, not too fine-grained, and, above everything, clean. If it contains loamy, clayey, or vegetable matter it should be well washed before use. Sand which is not clean reduces the strength of the concrete and may even spoil it entirely.

The gravel also should contain no foreign matter. Stones should generally be washed. The water used in mixing should be clean and free from scum. Porous, water-absorbing stone (brick, sandstone, etc.) should be soaked in water before use. Soft or brittle stones should not be used for concrete, as their strength would not equal that of the cement mortar forming the rest of the concrete.

For cement mortar cement is mixed with from one to four parts of sand. For the smooth coating of foundations mixtures in the ratio 1 : 3 or 1 : 4 are sufficient.

In preparing cement mortar the measured amount of cement is sifted over the required quantity of sand, and the mixture is then stirred together until a

mass of uniform colour results. Only then should water be added, the mixing being continued all the time.

The following table (Table 18) shows the quantities required for the various qualities of mortar :—

TABLE 18.

Proportions of Mixture.		One Cubic Yard of Mortar requires:			
Cement.	Sand.	Cement (lbs.).	Cement stated in No. of 1 Cwt. Sacks.	Sand (Cubic Yards).	Water (Gallons).
1	1	1,600	14·3	·67	78
1	2	1,060	9·5	·89	72
1	3	790	7·1	1·0	69·5
1	4	625	5·6	1·05	68·5

Concrete consists of a mixture of cement, gravel or sand and broken stone. These materials are mixed in various proportions, according to the strength required. Gravel, which should consist of all sizes of pebbles between $\frac{1}{4}$ inch and $2\frac{1}{2}$ inches in diameter, is the most economical constituent, as it provides the smallest proportion of gaps to be filled by the cement mortar. Experiment has shown that such gravel contains about 35 per cent. of gaps and that the densest and firmest concrete is obtained when twice as much gravel as sand is used.

If, owing to shortage of gravel, broken stone (road metal) has to be used instead, more cement mortar will be required, as the gap spaces in this case amount to about 50 per cent. It is advisable not to use broken stone of uniform size like road material, but to make it include all sized pieces up to 2 inches in diameter.

Often a natural mixture of gravel and sand can be obtained and used with advantage. Its proportion of gravel can be determined by sifting through a sieve of about $\frac{1}{4}$ inch mesh. More gravel or more sand can then be added, according to the proportions desired.

It must be remembered that concrete consisting only of gravel or stones and cement is far weaker than when sand is present as well.

When preparing concrete the sand is spread out on wooden boards or on an iron sheet ; cement is then sifted over it as uniformly as possible and the whole is well mixed whilst dry ; then water is added, mixing all the time, until the consistency of moist earth is attained ; finally the previously prepared gravel or broken stone is added and the whole well mixed again. In making the mixture accurate box measures should be used.

The ramming home of the concrete is a point of much importance. Only well-rammed concrete can attain the required density and the consequent strength.

The ramming should be carried out on each layer of 6 inches or 8 inches in thickness and should be continued until a layer of water appears on the surface.

It is sometimes necessary to add a layer of new concrete to an existing concrete structure. In such a case the old surface should be well damped and then covered with a thin layer of pure cement. An intimate combination of the two surfaces will then take place.

The following table (Table 19) shows the usual proportions employed and the quantities required when using gravel and broken stone of graduated coarseness and containing about 35 per cent. of gap spaces :—

TABLE 19.

Proportions.			Breaking Stress, after about 30 Days, in lbs. per sq. inch.	One Cubic Yard of Hard Rammed Concrete requires:			
Cement.	Sand.	Gravel.		Cement (lbs.).*	Sand (Cubic Yards).	Gravel (Cubic Yards).	Cement in 1 Cwt. Sacks.
1	2	4	2,950	530	·45	·9	4·75
1	3	6	2,350	340	·45	·9	3·05
1	4	8	2,000	255	·45	·9	2·25
1	5	10	1,700	212	·45	·9	1·9
1	6	12	1,350	160	·45	·9	1·43

* Specific gravity of the cement = 1·4.

When using coarse broken stone of uniform size and showing about 50 per cent. of gap spaces the proportions are as shown in Table 20 :—

TABLE 20.

Proportions.			Breaking Stress, after about 30 Days, in lbs. per sq. inch.	One Cubic Yard of Hard Rammed Concrete requires:			
Cement.	Sand.	Broken Stone.		Cement (lbs.).*	Cement in 1 Cwt. Sacks.	Sand (Cubic Yards).	Broken Stone in Cubic Yards.
1	2	3	2,550	680	6·1	·6	·9
1	3	4·5	2,000	475	4·25	·6	·9
1	4	6	1,700	375	3·35	·6	·9
1	5	$7\frac{1}{2}$	1,350	340	3·05	·6	·9
1	6	9	1,150	240	2·15	·6	·9

* Specific gravity of the cement = 1·4.

If concrete is to be laid under water it must contain equal quantities of sand and gravel. Even then the strength is never equal to that of rammed concrete

with twice as much gravel, because the mortar and gravel cannot get into close intimacy without ramming.

In agitated or flowing water concrete will not set, as the motion prevents a uniform distribution of the cement. The water must, therefore, either be diverted or brought to rest.

Only as much concrete should be prepared as will be wanted at the time. Before it dries the surface of the concrete should be given a smooth finish.

Concrete work can be carried out in frosty weather at temperatures down to — 3° C., but the work should be done very quickly, and very little water should be used in mixing the concrete. The finished work must be covered up, as in the case of hot weather, to prevent too rapid drying.

Concrete structures must be carefully superintended, as much bad work is carried out for want of knowledge or through carelessness.

The materials—sand, cement, gravel, and clean water—have often to be transported from a distance, and it can easily be understood that the workmen through hurry or to save trouble will be tempted to make up any shortage by employing the nearest substitute, such as the excavated soil, etc. Many such cases have occurred, as well as cases where large unbroken stones, that happen to have been dug up in the excavation work, have been thrown into the mass of concrete to take the place of some of the proper gravel or broken stone. Sometimes also the dry materials are placed in the hole without a drop of water and damping is subsequently carried out by pouring water on the surface. The ramming home is often also omitted in order to save trouble or to economise material, for the greater the amount of ramming the greater the amount of material required to fill a given space.

It is a common plan to attempt to economise on the expensive cement, and this fraud is difficult to discover after mixing has taken place.

Sometimes only the outer and upper portions of the structure to a depth of 10 or 12 inches are of concrete whilst the rest has been filled in with heavy stones, earth, etc. In other cases the quality of the concrete used for the lower portions is not up to the specification. Such irregularities can only be avoided by thorough supervision.

9. POLE CONSTRUCTION.

(a) Wooden Poles.

Red fir is the most commonly used wood, but American pitch-pine, larch, and Scotch fir are also used. The poles should be straight stems of sound growth, without knots or splits, and not spongy or showing cracks across the end sections. Stems showing a particularly twisted or spiral growth should be rejected, as they tend to twist still further as they dry, and so disturb the hang of the line. The diameter of the ground level should, in accordance with equation 38, be 1·5 times the top diameter. The taper for ordinary lengths should, therefore, amount to about 1 inch in diameter in 8 feet. Variations from the above diameters amounting to $\frac{1}{2}$ inch are permissible if the average for all the masts in a consignment tallies with the specified figures. When the mast section is not quite circular the smallest diameter should be measured. In the length a variation of $\pm$ 1 per cent. should be allowed.

The top of the mast is usually cut conical in order to let the water run off better, and the surface is painted over with hot tar or asphalt. This offers sufficient protection usually and no additional cover is required.

For supervision and statistical purposes each pole should be provided, at a height of about 5 feet, with a branded table giving the length, diameter at the top, year of erection, and name of the firm supplying it.

Impregnation of wooden masts is resorted to in order to lengthen their life. The best known preservative processes are impregnation with copper sulphate, with zince chloride, with creosote and kyanising with sublimate of mercury.

The German Post Office statistics dealing with six and a half million poles between the years 1852 and 1909 show that 83 per cent. of these were treated with copper sulphate, ·2 per cent. with zinc chloride, 4·4 per cent. with creosote, ·1 per cent. with various other compounds, 11·9 per cent. with sublimate of mercury, and ·4 per cent. received no preservative treatment. The same statistics show that the average life of the poles treated with copper sulphate was 11·7 years. Figures published by the Bavarian telegraph authorities show that kyanised poles have a life of 17·5 years. The British Post Office results for creosoted poles show that an average life exceeding thirty years can be counted on with these when the process is carefully carried out.

If these lengths of life are compared with that of an untreated pole (seven to eight years) it will be seen that the impregnation, which only adds 12 per cent. or 15 per cent. to the cost of the pole, is of decided value.

The widespread use of the copper sulphate process on the Continent is partly due to the fact that it was the first and, for a long time, the only process known,

and partly because the better (kyanisation) process involves a long period of drying, thus entailing the carrying of a large stock. In recent years, however, the kyanising process has spread rapidly. Thus, in the German Post Office between 1903 and 1909 the increase amounted to 6·5 per cent. of all the poles used. In the same time interval the number of masts treated by the creosote process increased to 1·4 per cent. In England most of the overhead transmission work has been done with poles creosoted by the Bethell or the Rüping processes.

The antiseptic action of the copper sulphate solution is comparatively weak. Experiment has shown that pieces of wood treated with a $2\frac{1}{2}$ per cent. solution of copper sulphate were no longer free from fungoid growths after two months, whilst pieces soaked for one hour in a 1 per cent. solution of sublimate showed no sign of fungus even after six months.

The copper salts in copper sulphate do not possess the power to form insoluble or nearly insoluble compounds with the constituents of the wood. The impregnation is, therefore, very liable to be drawn out of the wood. This is especially objectionable in chalky ground, where the carbonic acid in the water rots the wood.

Impregnation with Copper Sulphate.

This process was discovered in 1841 by Boucherie. A 1·5 per cent. solution of copper sulphate is driven into the stem from the root end under its own hydrostatic pressure (a head of 10 or 12 yards). The sulphate forces the sap out at the other end of the pole. The process is continued until in place of the sap the blue impregnating solution flows out.

As the impregnating liquid must find the sap in a fluid and unchanged state, only newly-felled wood can be treated in this way. In the spring, when the sap is thin and fluid, not more than ten days should intervene between the felling and the impregnation, and in summer, when the sap is viscous, not more than eight days. A period of ten or twelve days is required for the impregnation of a 30-foot pole.

Impregnation with Creosote.

The well-dried or seasoned pole is placed in a vacuum chamber for one hour and the previously heated creosote is then forced in under a pressure of 90—120 lbs. per square inch. In this way the cells are completely filled with oil, and this means a considerable outlay on creosote. In the Rüping process the creosote is withdrawn later, so that only the walls of the cells remain coated with the oil. This is effected by raising the pressure in the chamber to about 220 lbs. per square inch, and after a sufficient time has elapsed the oil is drawn out of the chamber, and then the compressed air in the wood drives the excess oil out of the cells.

The Sublimate of Mercury Process.

The powerful antiseptic action of chloride of mercury makes it possible to impregnate wood sufficiently by simply laying it in a $\frac{2}{3}$ per cent. solution of it

placed in wooden troughs free from iron supports. Kyanising (discovered in 1832 by Kyan) takes eight to ten days. Only fully-dried wood, in which all the crack formation resulting from drying is completed, can be subjected to this process.

The dangerous section as regards mechanical stress is that at the surface of the ground, and here the alternations of dryness and damp are most severe and damage to the wood occurs most quickly. It has, therefore, always been this point to which protective treatment has been most applied. Besides many expensive and more or less effective suggestions two simple devices have proved satisfactory. One is due to Wingenfeld, and consists in applying several coatings of a hot mixture of asphalt and tar to the dangerous portion of the pole. The layers are held in position by flat jute bands wound round the pole. The cost of treating a pole in this way at the point of erection is only about one shilling. The process is specially applicable to existing pole lines. The soil around the pole is removed to a depth of 15 or 20 inches, and after the pole has been left exposed in this way for a few days to dry the protective covering is applied. The second method (due to Messrs. Himmelsbach, of Freiburg) consists in applying a layer of special protective material called "Stockschutz" to the portion of the pole on both sides of the ground level, as shown in Fig. 83. Wooden poles are treated in this way at the following prices :—

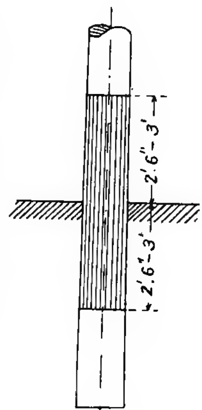


Fig. 83.

TABLE 21.

Length of Pole (feet) :—	26	29·5	32·5	36	39	42·5	46	49	52	56	59	62	65-82
Protected height . .	5	5	5	5	5	5	5	6	6	6	6	6	6
Lengths under ground .	5	5	5	5·25	5·5	6·25	6·5	6·8	7·5	7·8	8·2	8·8	9
Free length . . .	2·5	2·5	2·5	2·75	3·1	3·75	4·1	4·25	4·6	4·9	5·2	5·8	6·2
Price in shillings . .	1·6	1·8	2	2·2	2·4	2·6	2·8	3	3·2	3·4	3·6	3·8	4

The following table (22), on page 110, shows the cost of impregnated wooden poles using Kyan's (sublimate of mercury) process and Rüping's (creosote) process :—

(*b*) A AND H POLES.

Single wooden poles are not suitable for long-span lines owing to the heavy wind stresses. In such cases double masts in A form (Fig. 31) or in H form (Fig. 32) can be used. The latter is less often used in power transmission work than the A pole, which is fairly commonly used for lengths of span up to 500 feet.

The strength of an A pole at right angles to the line direction is four or five times as great as that of a single pole of the same diameter if the spread of the feet

TABLE 22.

Length (feet) :—	26			30				33			
Diameter at top (inches)	5—6	5½—6¼	6—6¾	5½—6¼	6—6¾	6¼—7	6¾—7½	6—6¾	6¼—7	6¾—7½	7—8
Price :											
Kyan (shillings) .	8·9	9·9	10·65	12	13·3	15	16·4	15·05	16·6	19·1	20·8
Rüping (shillings) .	9·1	10·1	10·9	12·25	13·6	15·3	16·75	15·4	17	19·6	21·25

Length (feet) :—	36				39				43			
Diameter at top (inches)	6—7¾	6¼—7	6¾—7½	7—8	6¼—7	6¾—7½	7—8	7½—8¼	6—6¾	6¼—7	6¾—7½	7—8
Price :												
Kyan (shillings) .	18·3	19·55	22·4	24·9	22·8	25	27·7	30	24·7	25·85	29·5	32·55
Rüping (shillings) .	18·7	20	22·85	25·45	23·3	25·6	28·25	30·65	25·2	26·35	30	33·2

Length (feet) :—	43		46					49					
Diameter at top (inches)	7½—8¼	8—8¾	6¼—7	6¾—7½	7—8	7½—8¼	8—8¾	6¼—7	6¾—7½	7—8	7½—8¼	8—8¾	8¼—9
Price :													
Kyan (shillings) .	35·2	38	29·1	32·3	36·45	38	41·7	34	37·6	40·6	44	48	51·6
Rüping (shillings) .	35·9	38·7	29·7	32·9	37·2	38·75	42·5	34·65	38·3	41·4	44·8	49	52·6

is made equal to about one-eighth of the length of the pole and if the two poles are firmly bound together top and bottom. The strength can be still further increased by fixing a cross-bar a third or half the way up the pole. The wood used for this cross-bar, as well as that used for connecting the feet, must be hollowed out to fit the round poles. The connection is made with $\frac{5}{8}$ or $\frac{3}{4}$ inch bolts. The tops of the poles must be bevelled off to suit their slope, and can be fixed together by two bolts or by a hard wood key block held by screws. The bedding surface of the bolt head and nut must be made ample by the use of thick washers.

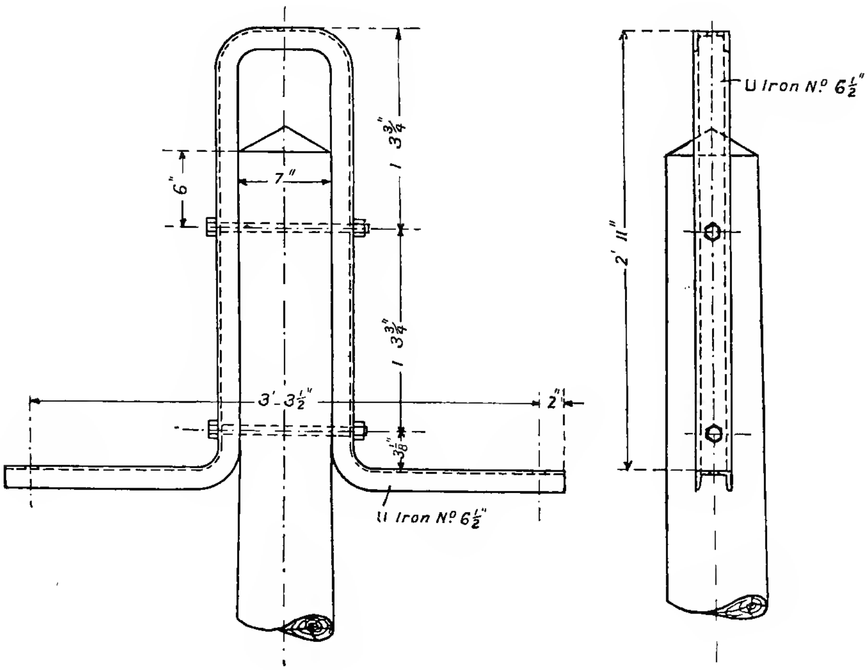


Fig. 84.

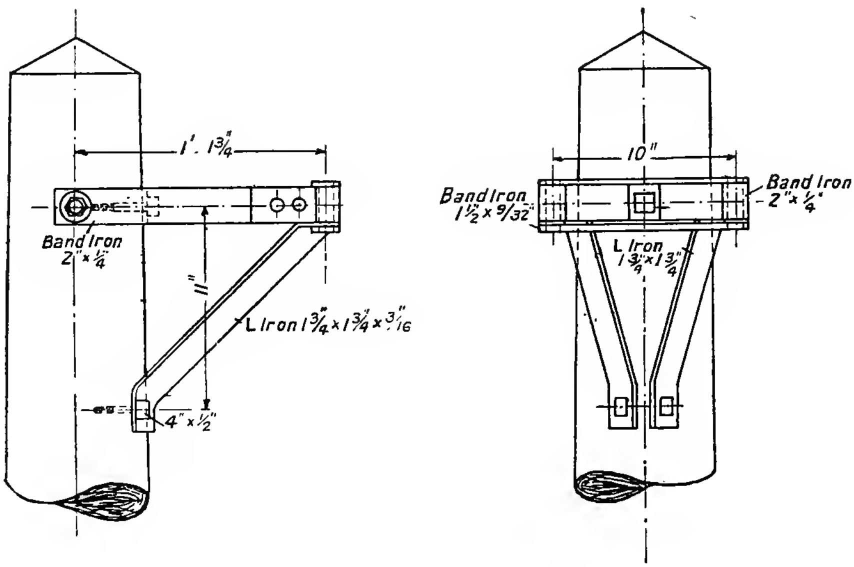
The usual relation of length of pole to spread of feet, 1 : 8, is a compromise between the requirements of economy and those of strength. Increased spread adds to the stability of the pole, as is shown by formulæ 49 and 50.

The use of wooden poles at corners or as strain masts or the combining of several A poles is not advisable. The appearance is unsatisfactory and the saving as compared with an iron mast is small, whilst the latter is decidedly safer and costs less to maintain.

Pins and Cross-Arms.

The shape and size of the insulator pins and the cross-arms on which they are carried is determined by the distances to be maintained from wire to wire and from wire to pole, and also by the forces which have to be withstood.

The simplest form is that of the bent or swan-neck pin shown in Fig. 47, provided with a wood-screw end and screwed direct into the pole. The insulator should be so placed that the line is attached at the same height as the screw end of the pin so that the tension of the line shall not tend to twist the pin.



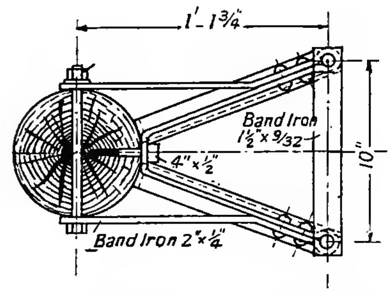


Fig. 85.

For fixing in walls the wood-screw is replaced by an end shaped as shown in Fig. 48. These hooked pin supports can be employed for voltages up to 10,000. With higher voltages the necessary distance between the rim of insulator and the back of the pin can only be attained safely by the use of excessively thick iron sections. In such cases, therefore, straight pins mounted on cross-arms are preferable. Fig. 84 shows one such arrangement. Here a U-shaped structure of channel iron or bar iron is placed on the top of the mast. This arrangement can also be used for straining the wires to. The length of mast can be reduced by about 1 yard as compared with that required for the swan neck bracket. The price is from 2*s.* 6*d.* to 3*s.* 6*d.* each, excluding insulators and pins.

Other common arrangements are shown in Figs. 85 and 174. The former shows the construction suitable for two insulators to which a line is to be strained. The same method can be used on A poles when an earthing wire is to be carried at the top of the pole. A cap carrying the earthing wire is placed over the top of the double poles where they are screwed together. A single insulator can be fixed

to a wooden pole as shown in Fig. 86. This consists of a couple of bent bar-iron clamps separated by a length of pipe as a distance piece at the crossing point. They are fixed to the pole by coachscrews or bolts or by a collar

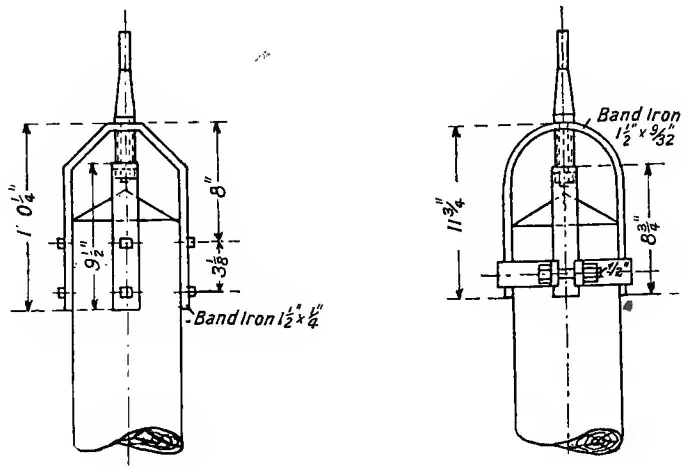


Fig. 86.

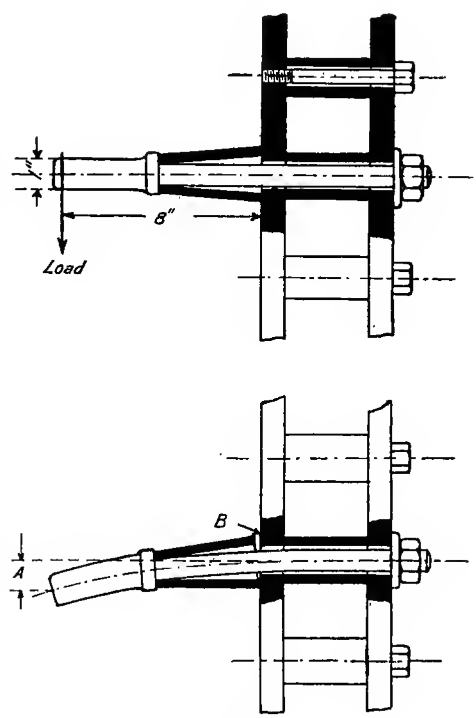


Fig. 87.

For small tensions straight pins made up of ordinary bolts, such as are obtainable in all lengths and diameters, can be used. The pin diameter should be $\frac{1}{16}$ to $\frac{1}{8}$ inch smaller than the insulator thread. When the shank of the straight bolt is insufficient for the forces involved a conical bolt as shown in Fig. 46 is employed. For large insulators and heavy pulls the form shown in Fig. 45 can be used. The insulator pin rests on a cast-iron mantle subjected to compression. The short pin above the mantle takes up the bending moment, whilst the longer pin inside the mantle is only subjected to tensile stress, so that great loads can be safely carried with comparatively small dimensions. In order to reduce the brush discharges the mantle has sometimes been made of porcelain.

In order to determine the strength of this type of pin load tests have been

carried out as shown in Fig. 87. The load was applied at a distance of 8 inches from the cross-arm, corresponding to the normal distance at which the tension on the insulator acts. The deflection A produced at the end of the pin and the amount B by which the cast-iron mantle was raised from its seating were measured and found to increase as follows :—

Load. Lbs.	A Inch.	B Inch.
1,770	·07	0
2,220	·138	0
2,650	·212	0
3,100	·31	·059
3,550	·55	·118
3,780	·98	·236

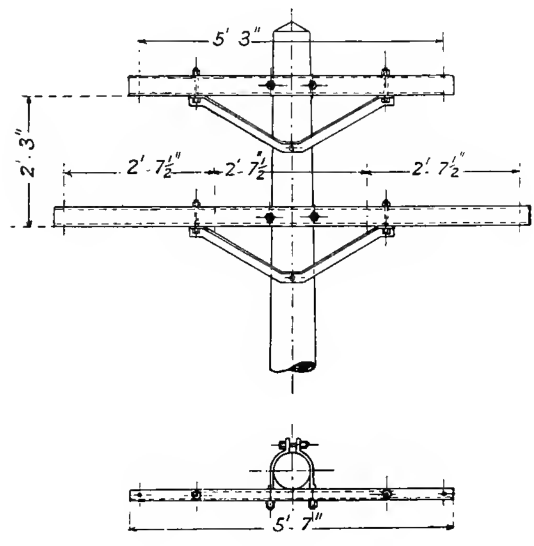


Fig. 88.

It will be seen that the bending of the pin begins at about 1,500 lbs. and increases almost proportionately up to 3,100 lbs. Above this load A increases very quickly. The measured deflections ·07 inch, ·138 inch, and ·212 inch correspond to calculated stresses of 28,000, 54,000, and 83,000 lbs. per square inch. The bending of the bolt within the mantle only commences at a load of 3,100 lbs.

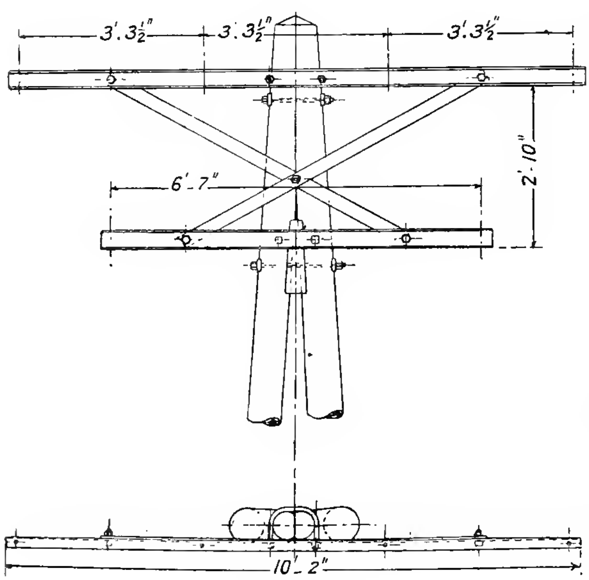


Fig. 89.

Present-day insulator pins are only made of best wrought iron or steel. At one time in America, and also in some European installations, wooden (oak) pins soaked in paraffin were used, but experience has shown that such pins become charred by discharges and are soon destroyed.

Cross-arms are generally made of channel iron or are built up from bar iron. Channel iron with wide flanges is the most satisfactory, as, besides offering a high resisting moment to

bending, the wide flanges enable the pins to be securely mounted. Figs. 88—90 show different methods of construction.

In the case of Fig. 90 the distance between the line and the cross-arm has been increased by bending up the ends of the cross-arm at right angles. This has been done in order to reduce the risk of short circuits or earth connections being brought about by birds settling on the structure. In some districts birds, especially rooks, have caused considerable trouble in this way, and this trouble has been practically removed by bending up the cross-arms in the way shown.

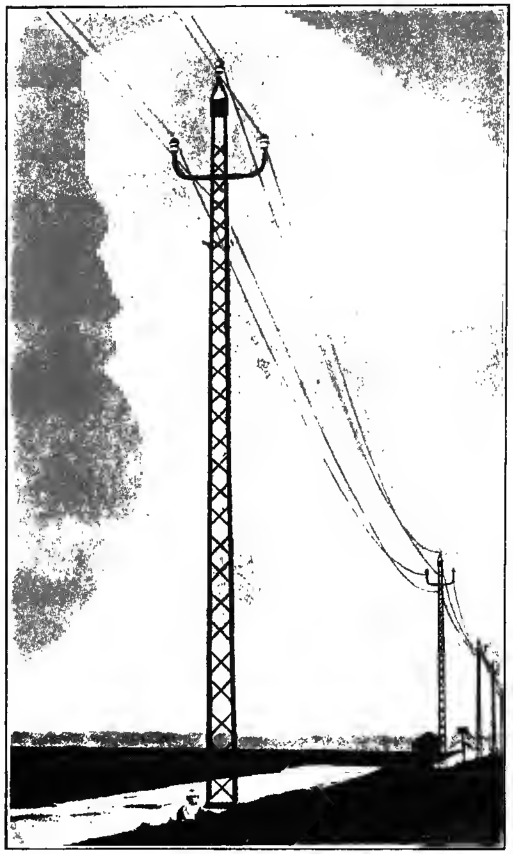


Fig. 90.

In the case of wooden poles the cross-arms are attached by means of iron bands as shown in Fig. 91, or as in Fig. 88 when a single size of band is to serve for poles of varied diameter. For the latter purpose the band is made in two parts bolted together, and the cross-arms are provided with long slots.

When the cross-arm has to carry heavy lines it is advisable to shape the channel iron to suit the curvature of the mast and to roughen the inner surface with chisel cuts. Cross-arms of considerable length are stiffened as shown in Figs. 88 and 89.

(c) Mast Feet.

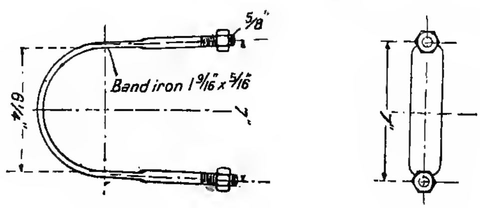


Fig. 91.

However well the mast is protected, it will be almost impossible to prevent the embedded portion of a wooden pole from deteriorating quicker than the post above the ground. It has, therefore, been suggested that wood should only be used for the upper portion and that the foot should be made of some more permanent material. In this way reinforced concrete feet with iron rails for gripping the mast or, more commonly, feet made entirely of iron in very varied shapes have come into prominence. The longer life thus attained by the upper

wooden pole (twenty to twenty-two years for kyanised poles) partly compensates for the additional cost involved in providing and maintaining the iron foot.

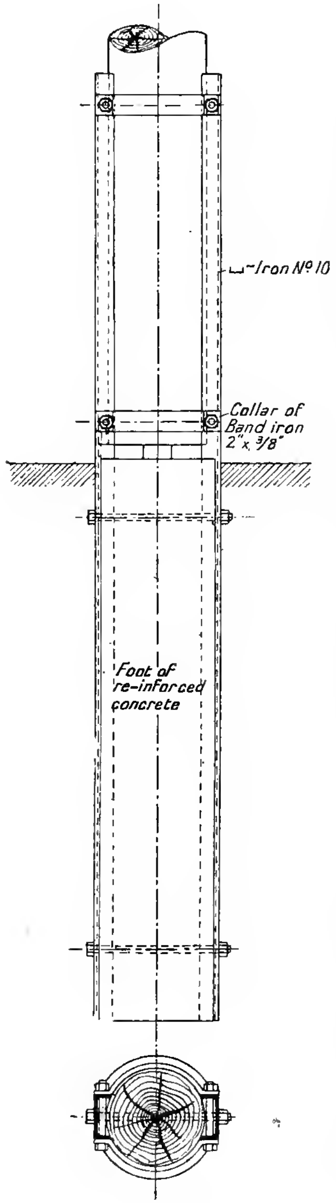


Fig. 92.

Mast Feet of Reinforced Concrete (Fig. 92).

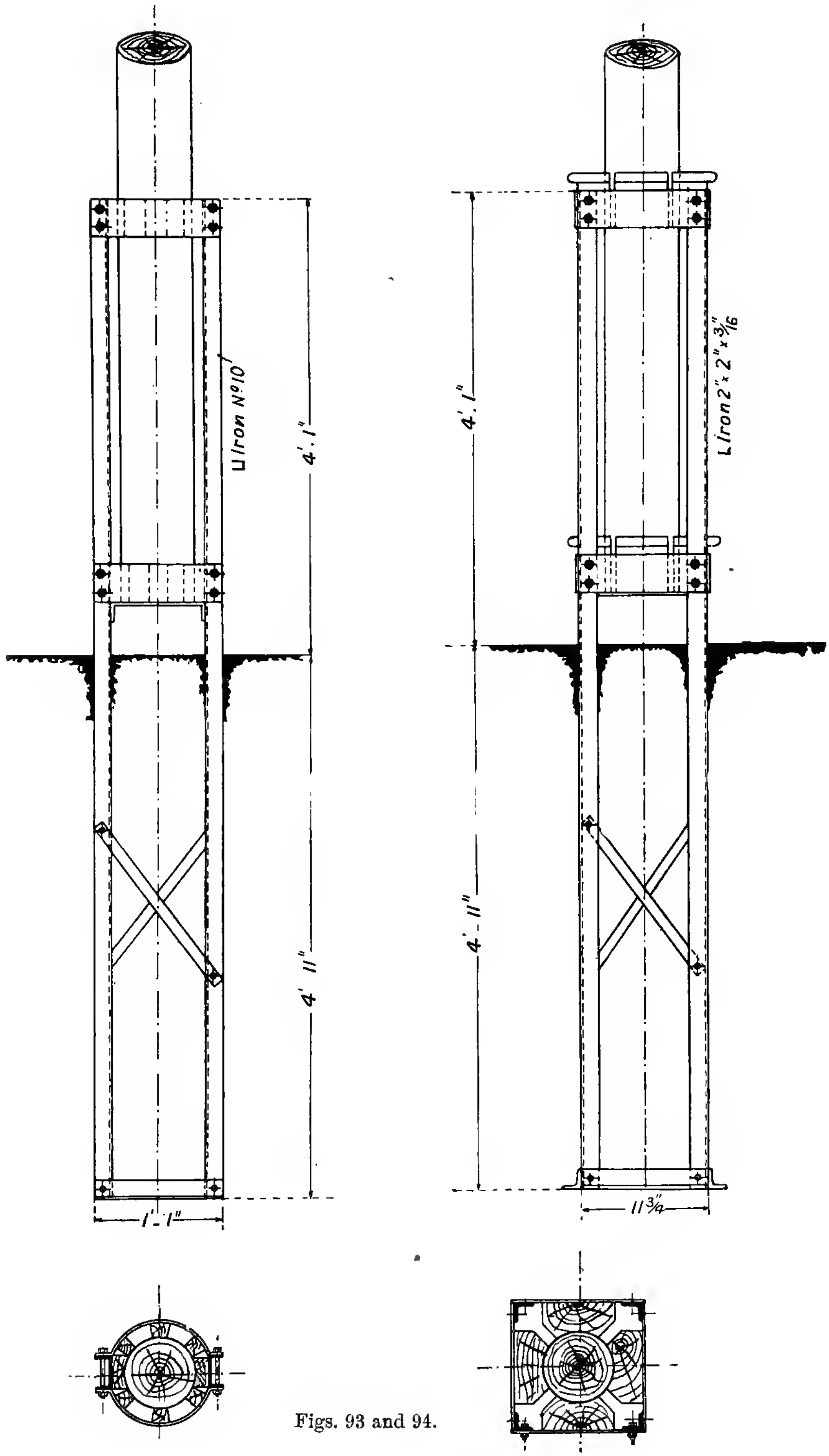
The two channel irons, which serve to support the pole, lie in longitudinal slots in the concrete column in the ground and project about 1 yard above the latter. Two collars attached to the channel irons embrace the pole. Wedges are driven between these collars and the pole, varying in size according to the diameter of the pole. In order that the bottom of the pole shall not touch the ground a small boss is provided at the top of the concrete column.

A special mast foot of this type has been patented by the Weserhütte of Bad Oeynhausen and is shown in Figs. 93 and 94. The mast foot is let into the ground sufficiently far to let the bottom of the pole clear the ground level by 4 or 5 inches. The channel iron type is used on straight stretches of line, but for corner masts or heavily-loaded masts the angle iron form is preferable. The latter is generally concreted into the ground, and in loose soil this has also to be done for the channel iron type. The considerable additional cost of the concrete foundation, however, generally makes it preferable to employ the ordinary wooden pole in a concrete foundation block in such cases.

Poles which have begun to rot can be given a new lease of life by fitting iron shoes as shown in Fig. 95. The soil around the mast is removed to a depth of about 20 inches and a strip of channel iron is driven into the ground hard against the pole and is temporarily fixed to the pole with coach screws. The pole is then shored up by means of struts and a notch is cut into it reaching about to the centre. A second channel iron is then driven into the ground opposite the first, and the two are securely bolted together through the pole and the remaining half of the pole is cut clear.

(*d*) Iron Masts.

Iron masts are practically always used for the higher voltages and for large power schemes, since in these cases their higher first cost is compensated for by



Figs. 93 and 94.

their longer life and the greater reliability of supply which they ensure. Such masts are of very varied design. The most important types are :

(1) Simple tubular masts.
(2) Multiple tubular masts.
(3) Lattice-work masts.
(4) Lattice-work structures or towers.

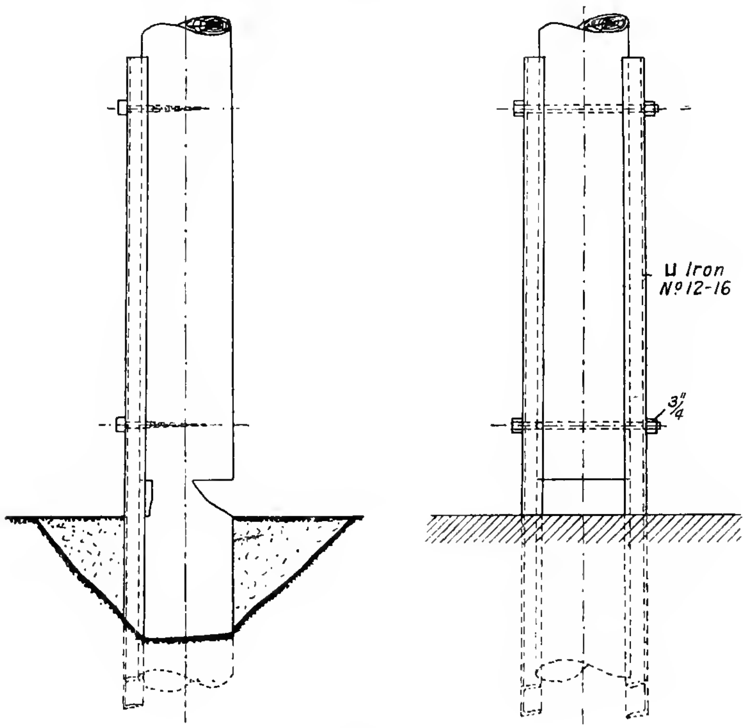


Fig. 95.

Simple tubular masts (Fig. 236) and multiple tubular masts (*e.g.*, masts made up of three simple tubular poles arranged at the corners of a triangle) are not very commonly used. Owing to their good appearance they are sometimes used in villages and the smaller towns, but for long-distance transmission schemes they are too expensive. These tubes are made in lengths up to 26 feet of wrought iron with a breaking stress of 55,000 to 57,000 lbs. per square inch or in Siemens-Martin steel with a breaking stress of 80,000 to 85,000 lbs. per square inch. The Mannesmann tubes are made of the latter material. The prices vary between 17*s*. and 30*s*. per cwt.

The smaller tubular masts are made in one piece, tapering towards the top and consisting of two or three lengths welded together. Larger masts are made up in sections shrunk together or held together by shrink rings.

Table 23 gives the dimensions and the allowable loads for Mannesmann tube masts of the forms I., II., and III. (Fig. 96).

TABLE 23.

Type Fig.	Dimensions in Inches.											Allowable Horizontal Load	Deflection Produced	Stress produced at the:			Weight of Mast in lbs.
	L	*l*	*a*	*b*	*c*	*d*	*f*	*g*	*h*	*i*	*k*	(lbs.).	(inches).	Bottom	Centre	Top	
														(in lbs. per square inch).			
I.	327	272	210	69	47½	6	5·6	5	4·65	4	3·65	222	4·5	13,200	8,000	5,700	296
I.	327	272	210	69	47½	7	6·6	5·75	5·4	4·5	4·15	333	4·35	14,300	9,300	6,100	350
I.	327	272	210	69	47½	7½	7·1	6·25	5·9	5	4·6	444	4·2	14,300	9,400	6,100	417
I.	338	285	224	69	47½	7½	7·1	6·25	5·9	5	4·6	555	5·5	19,500	11,700	7,700	432
I.	338	285	224	69	47½	8	7·5	6·25	5·9	5	4·6	666	5·25	18,800	14,000	9,000	485
II.	346	285	230	69	47½	9	8·5	7·5	7·1	6	5·6	888	5·15	21,500	13,000	8,600	560
II.	354	285	238	69	47½	9	8·5	7·5	7·1	6	5·6	1,100	5·5	22,800	16,000	10,500	650
II.	362	285	245	71	47½	10	9·5	8	7·6	6	5·6	1,340	4·75	23,800	15,800	11,500	710
II.	362	285	245	71	47½	11	10·5	9	8·6	7	6·6	1,550	4·25	20,800	14,300	9,500	830
II.	362	285	245	71	47½	11	10·5	9	8·6	7	6·6	1,780	4·8	23,800	16,200	11,000	830
III.	362	285	245	71	47½	11	10·5	9	8·6	7	6·6	2,200	5·5	28,000	19,000	12,800	960

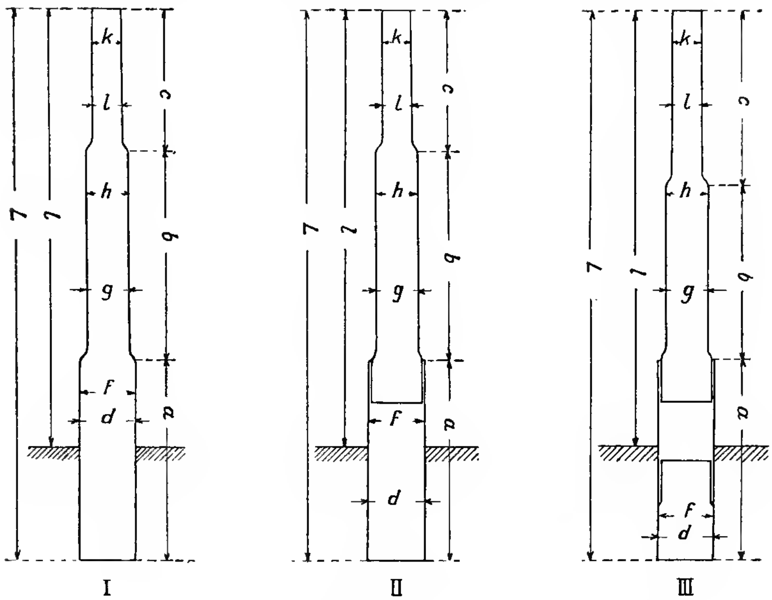


Fig. 96.

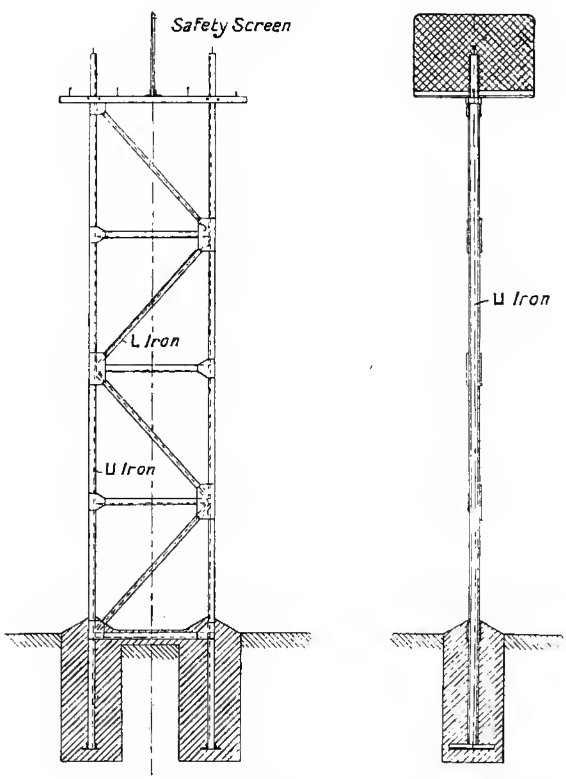


Fig. 97.

Multiple tubular masts have the advantage that they can be built up on the spot, so that the cost of transport and erection is less than for lattice-work masts, although the first cost is considerably greater. Their light and attractive appearance is their special advantage, however.

Lattice masts are made up of sectional wrought iron, usually channel or angle iron. In many cases the iron section to be used is determined by the object for which the mast is intended. For instance, elastic supporting masts (Fig. 97) are preferably made up of channel-iron sections, whilst strain masts and masts for heavy loads generally should be made up of angle-iron sections.

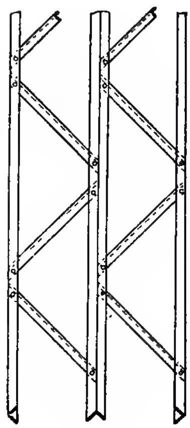


Fig. 98.

The diagonals of angle-iron lattice masts should be so arranged that, unless crossed diagonals are used, only two bars meet at any one junction point (Fig. 98). In the interests of good appearance the diagonals should be fixed on the inside of the angle irons, although the outside arrangement (Fig. 180) offers the advantage of easier and more reliable riveting work. Tall masts and those intended for heavy loads can be appreciably cheapened by reducing the sections of the tubes, diagonals, etc., towards the top. The correct distribution of the material can be determined by calculation.

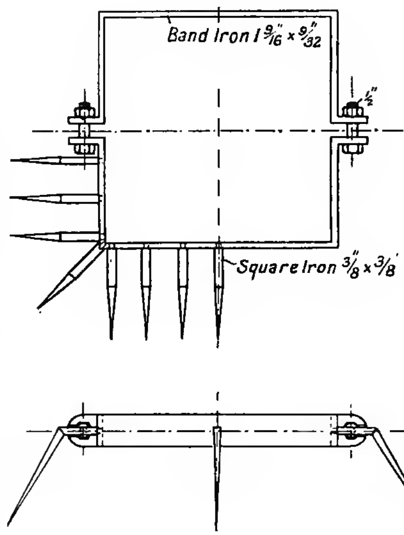


Fig. 99.

The rules of the V. D. E. limit the stress in iron structures to 21,500 lbs. per square inch. If Thomas wrought iron with a breaking stress of 57,000 lbs. per square inch is used, the factor of safety is about 2·5, and this figure should be maintained throughout the structure in normal cases. The deflection produced with the above maximum stress is not allowed to exceed 2 per cent. of the free length. This assumes that the drilling and riveting has been carefully carried out and that the rivets fit the holes closely. The rivet holes should not be punched but drilled. Besides the holes for the rivets holes must also be provided for fixing the description plate and the earth wire, and these holes should not be drilled in places where they will weaken the structure unduly.

Unauthorised climbing of masts can be prevented by fixing spiked collars (Fig. 99) round the mast at a height of about four yards. The height of these collars or *chevaux de frise*, must be kept the same on all the masts so that the width of opening inside the collar should be adjustable.

Tables 24 and 25 show the dimensions of some of the standard flat lattice-work masts and quadrangular lattice-work masts supplied by the Weserhütte Iron Company of Bad Oeynhausen. These masts are designed for a four-fold factor of safety, corresponding to a working stress of 14,300 lbs. per square inch. If greater or less stress is desired the load applied can be increased or reduced proportionately from the value given.

In these tables :—

L = gross length of mast in feet.
l = length above the ground level in feet.
l_1 = length underground in feet.
b = breadth at the top of the mast in inches.
B_0 = ,, ,, ground level in inches.
f = the theoretical deflection in inches.
G = approximate weight in lbs.

TABLE 24.—*Flat Lattice-Work Masts of Channel Iron.*

Allowable Load.	440 lbs.			880 lbs.			1,100 lbs.			1,350 lbs.		
l	16·3	26	39	16·3	26	39	16·3	26	39	16·3	26	39
l_1	3·9	4·9	5·2	5·2	6·5	6·5	5·2	6·5	6·5	5·2	6·5	6·5
L	20·2	30·9	34·2	21·5	32·5	45·5	21·5	32·5	45·5	21·5	32·5	45·5
b	3·75	3·85	5·1	4·6	4·6	5·1	4·75	4·75	4·9	4·8	4·8	5·6
B_0	8	11	18	11·5	15·5	21·5	11·5	15·5	21	11·5	15·5	21·8
f	2·05	4·7	5·1	1·77	4·7	5·5	2	4·7	5·8	1·8	4·1	6
G	305	465	850	355	530	1,100	430	640	1,320	510	760	1,540

TABLE 25.—*Quadrangular Lattice-Work Masts of Angle Iron.*

Allowable Load.	880 lbs.			1,350 lbs.			2,200 lbs.			3,350 lbs.			4,500 lbs.		
l	16·3	26	39	16·3	26	39	16·3	26	39	16·3	26	39	16·3	26	39
l_1	3·9	4·6	5·6	4·6	4·9	5·9	5·2	5·6	7·2	5·6	6·2	8·2	6·2	6·6	8·8
L	20·2	30·6	44·6	20·9	30·9	44·9	21·5	31·6	46·2	21·9	32·2	47·2	22·5	32·6	47·8
b	5	5·6	6	5·6	6	6·8	6·9	6·9	8	8·1	9·3	10·2	8·5	9·4	9·8
B_0	11·1	15·2	20·5	11·6	15·7	21·2	13·5	18·2	24·4	15·8	21·5	28	16·2	21·8	28
f	2	3 55	5·5	1·62	3·15	5·8	1·46	3·6	5·8	1·26	2·9	4·8	1	2·75	5·2
G	475	790	1,530	650	1,000	1,920	890	1,400	2,550	1,200	1,800	3,260	1,430	2,270	4,300

Such masts are supplied at from 11*s*. to 15*s*. a cwt., according to the weight of the individual masts and the number ordered at one time.

For the longer spans, for river crossings and for very heavy lines, complete ironwork structures and towers are used (see Figs. 101 and 102).

Frequently it is considered desirable to reduce the maximum sag of a line by loading it permanently by means of a weight sufficient to produce a constant tension equal to the maximum allowable tension. This maximum tension would occur, in the case of the long spans now under consideration, at — 5° C., with the additional load due to ice or snow. This is, however, also the condition for maximum sag if the line has been erected with a maximum stress of 23,000 lbs. per square inch in hard drawn copper wire (13,800 lbs. per square inch in stranded copper, cable.) The method of reducing the sag by means of weights would, therefore, be inapplicable unless the line happens to have been erected with lower stresses than the above—an unlikely occurrence in long-span lines.

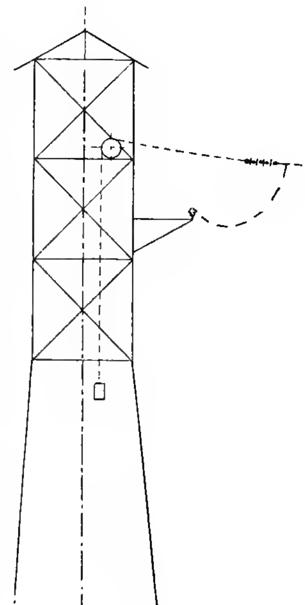


Fig. 100.

It has, however, already been pointed out that the allowance made for additional ice and snow load in the rules of the V. D. E. is not sufficient to cover abnormal cases, and loads of as much as ten or twenty times those values have been measured on occasion. These excessive loads are especially liable to occur at river crossings; consequently these are sometimes provided with a tension arrangement combined with a switch in such a way that as soon as the tension exceeds the allowable value the circuit is opened at the crossing and the line is made "dead." This switch is also actuated if a line breaks—the falling of the tension weight opening the switch.

Provision against excessive ice load can be more simply made by straining the wires, which should preferably be of copper-clad steel (monnot metal), so that at — 5° C. with normal ice load the stress is only one-half or two-thirds of the allowable value and by raising the height of the masts somewhat so as to permit increased sag.

If special straining weights are to be employed the arrangement must be such that the weight, the rope, and the pulleys are easily accessible, and not alive, so that they can be adjusted without interfering with the operation of the line. The insertion of a strain insulator between the line and the tension rope (see Fig. 100) enables this to be done.

Iron structures should be painted over with liquid cement at those portions which are to be let into concrete. At other parts they should receive one coating of rust-proof paint (bitum nous paint) or red-lead. This painting should be repeated every two or three years, and as this cannot generally be done with the line alive it is necessary to switch it off, at any rate whilst the top of the mast is being painted. In order to avoid this difficulty it is common practice to galvanise the upper portion of the mast down to about 1 yard below the lowest cross-arm. The lower part of the mast can then be painted whilst the line is in use, if reasonable care is taken.

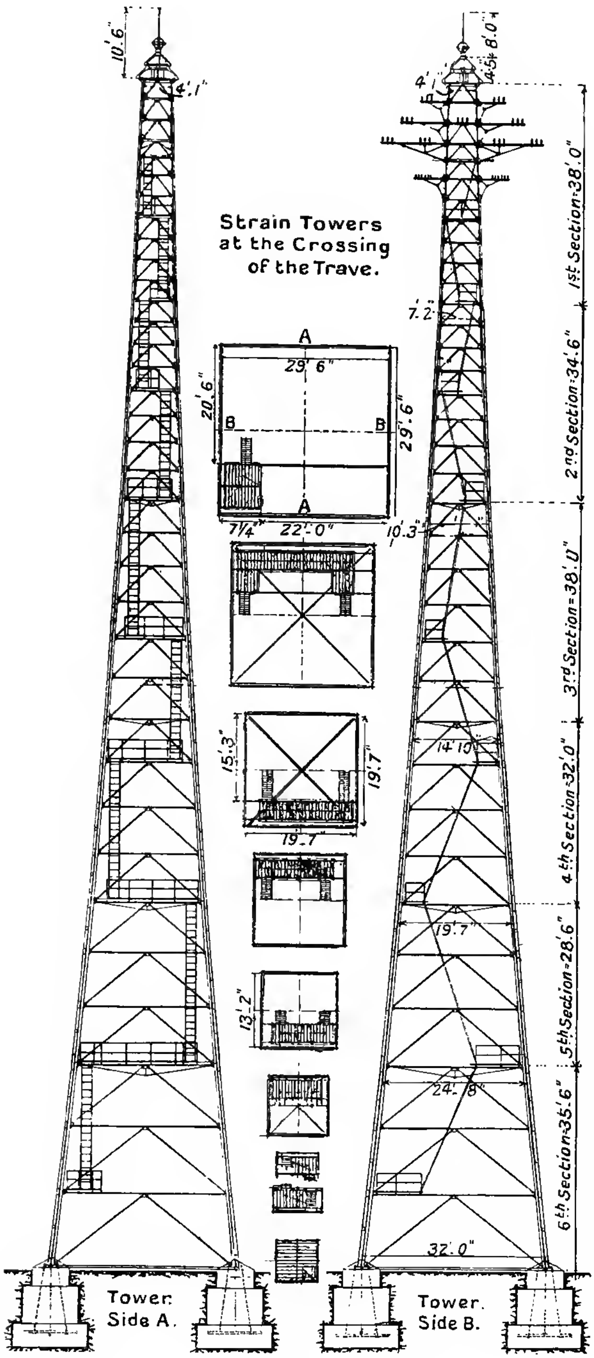

Strain Towers
at the Crossing
of the Trave.
Tower
Side A.
Tower.
Side B.
1st Section-38'.0"
2nd Section-34'.6"
3rd Section-38'.0"
4th Section-32'.0"
5th Section-28'.6"
6th Section-35'.6"
29'.6"
22'-0"
19'.7"
14'.10"
24'.8"
32'.0"

Fig. 101.

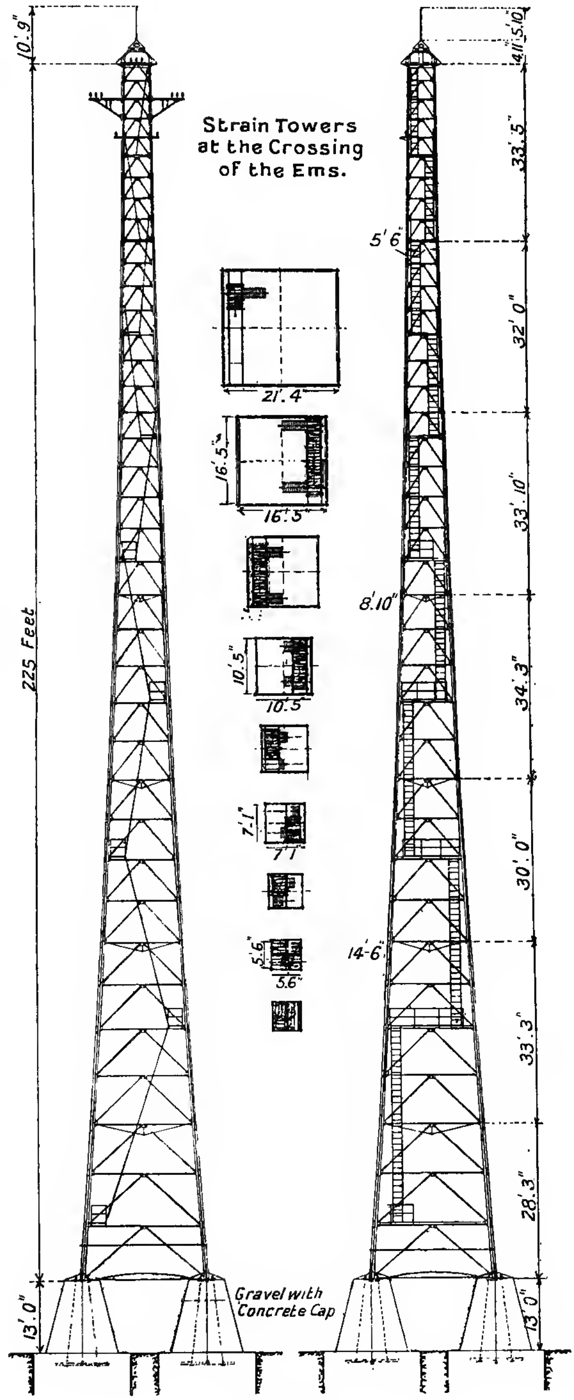

Strain Towers
at the Crossing
of the Ems.
10'.9"
225 Feet
13'.0"
21'.4"
16'.5"
16'.5"
10'.5"
10'.5"
7'.1"
7'.1"
5'.6"
5.6"
Gravel with
Concrete Cap
5'6"
8'.10"
14'-6"
33'.5"
32'.0"
33'.10"
34'.3"
30'.0"
33'.3"
28'.3"
13'.0"

Fig. 102.

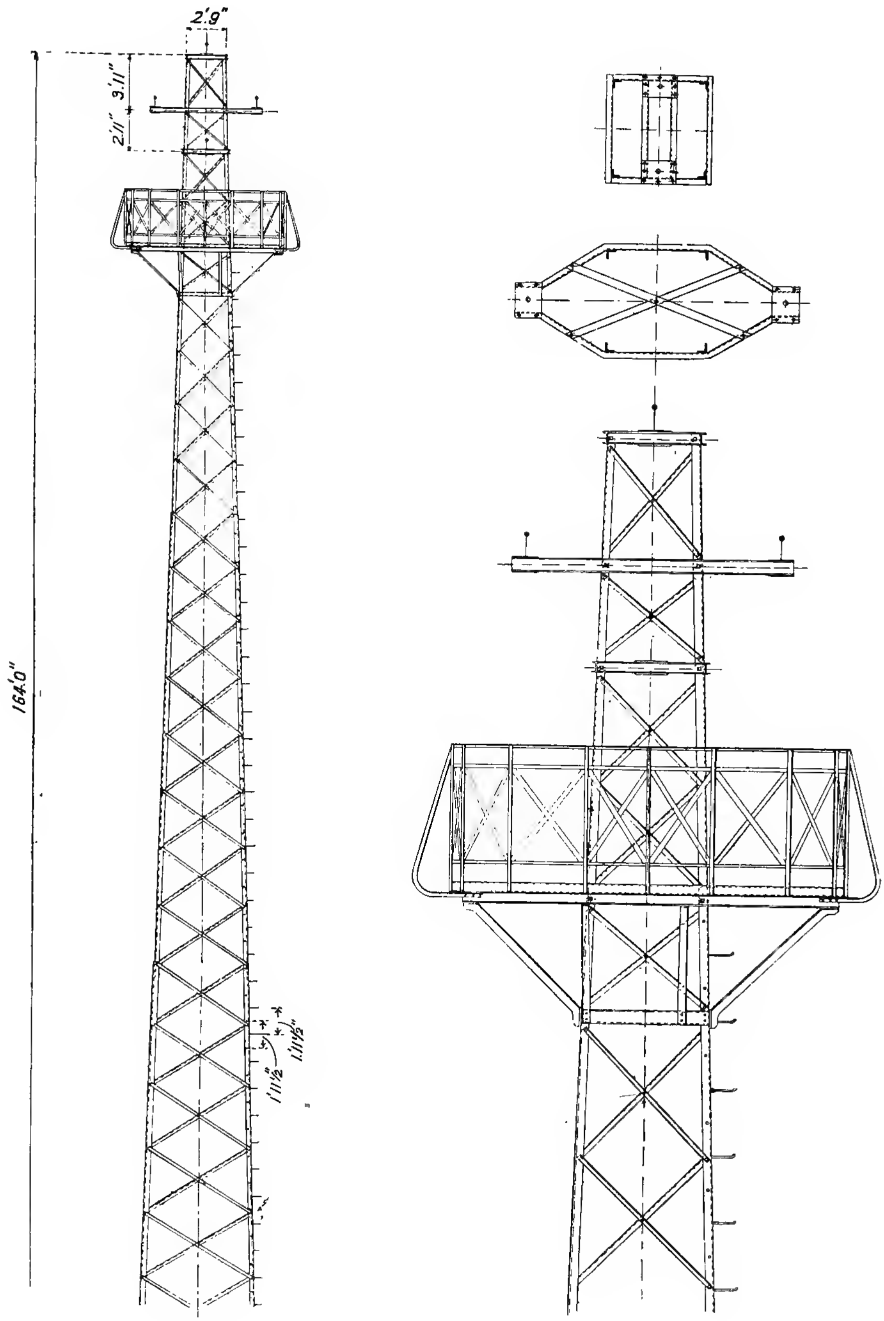


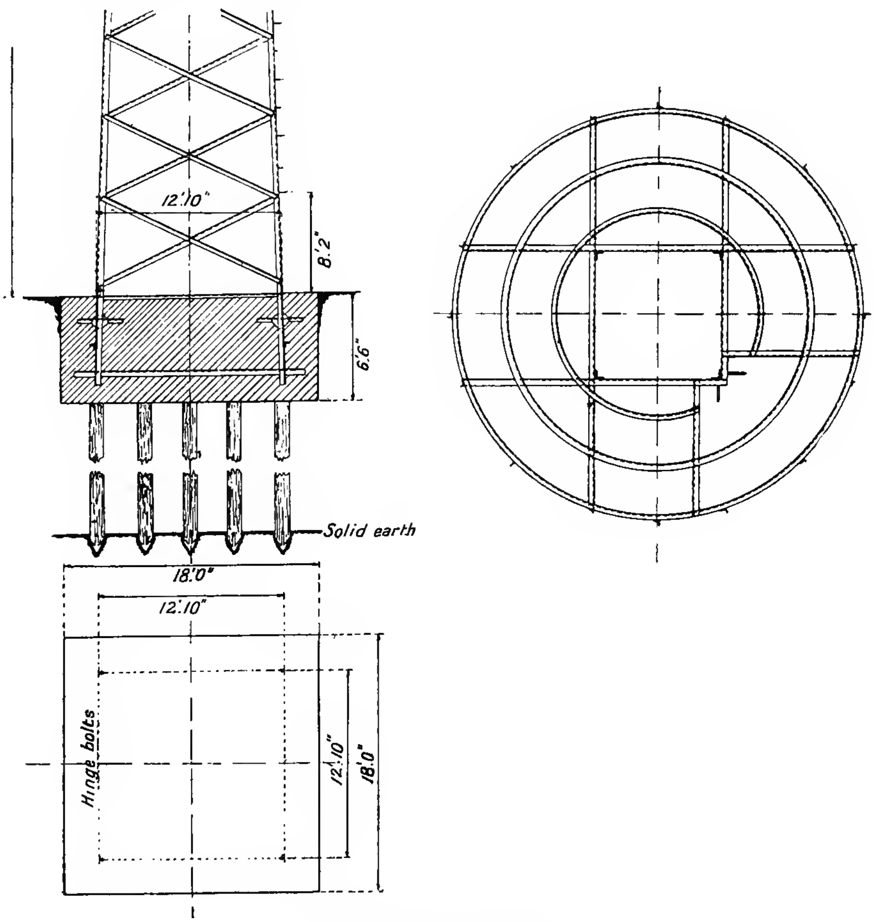
Fig. 103.

Examples from Practice.

The structures described below are some carried out by the Weserhütte of Bad Oeynhausen.

Fig. 101 shows a tower 206 feet high to the underside of the cap, and 216·5 feet high overall, used by the Siemens-Schuckertwerke of Berlin for a high-tension line crossing of the river Trave at Herrenwyck. Besides wind pressure it has to withstand two pulls at right angles to one another—one being 16,600 lbs. and the other 3,500 lbs. The weight, including that of the anchoring arrangements, amounts to about 19 tons.

It was erected in mid-winter during violent storms and without any scaffolding, working upwards from the base. Ordinary ladders are provided for mounting this tower for inspection purposes. Platforms are inserted at intervals to avoid risk of fatigue when climbing.



Foot of Tower in Fig. 103.

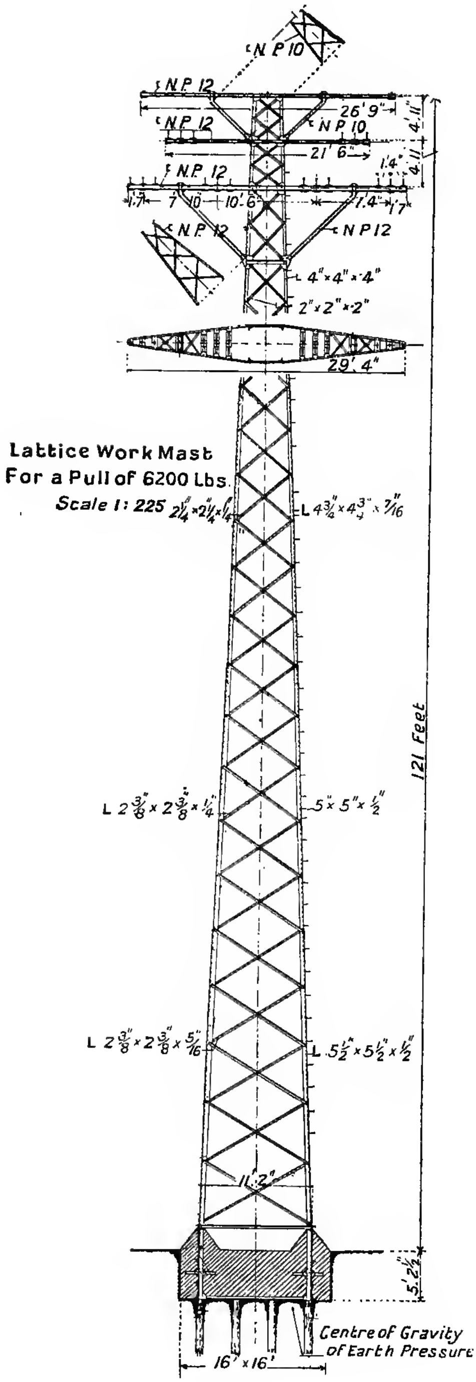


Fig. 104.

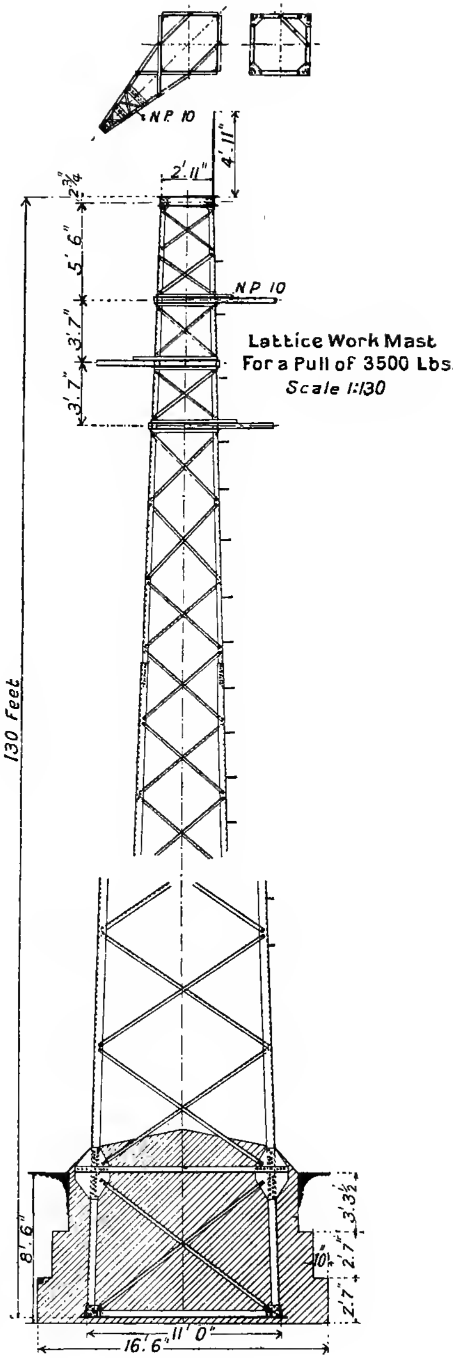


Fig. 105.

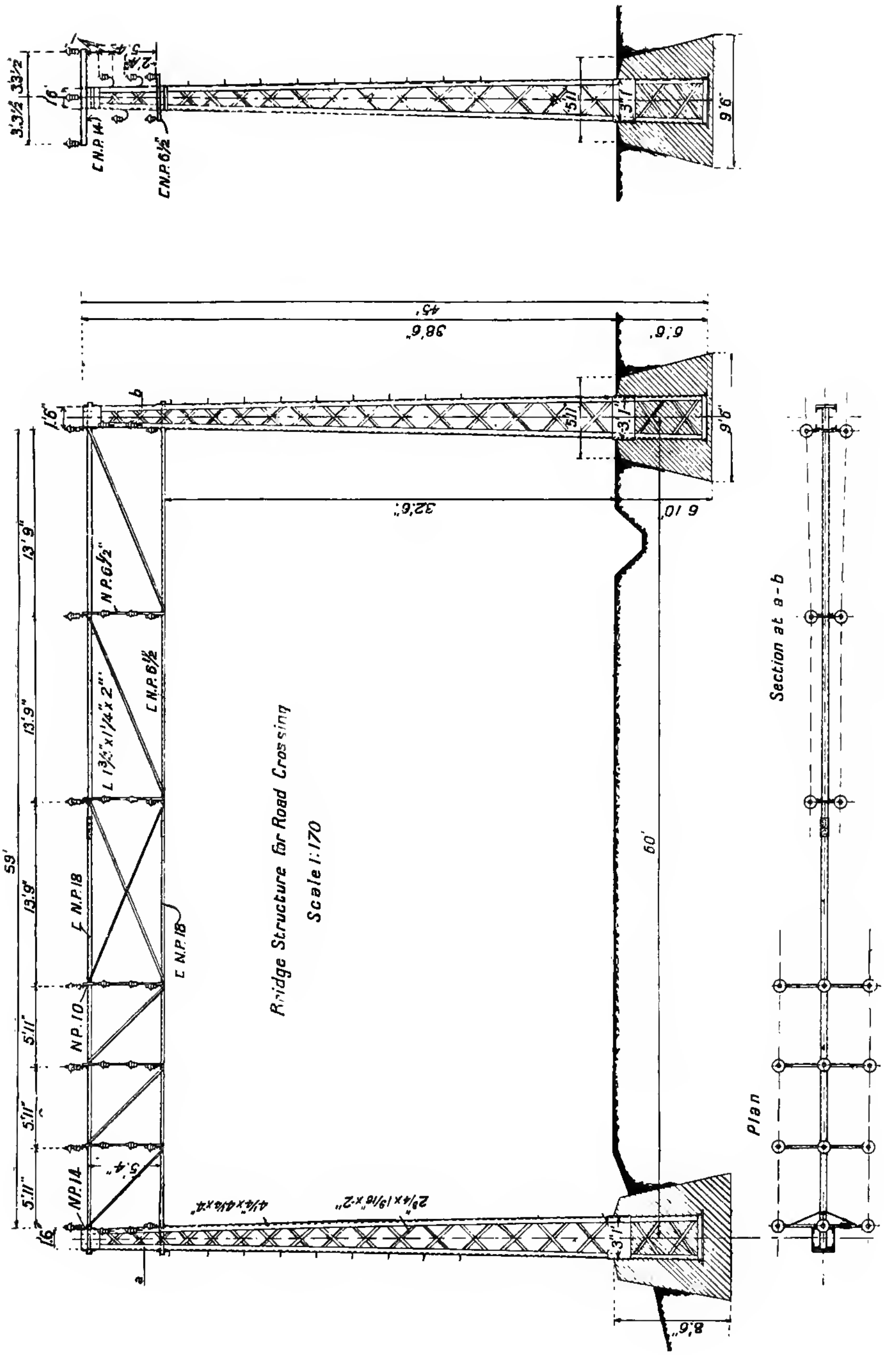

Bridge Structure for Road Crossing
Scale 1:170
Section at a-b
Plan

Fig. 106.

Fig. 102 shows a similar structure used by the Siemens-Schuckertwerke for a crossing of the river Ems. The total height of the tower itself is 235 feet 9 inches. Owing to the frequent occurrence of floods and floating ice the foundations project 13 feet above the ground level, so that the top of the tower is 248 feet 9 inches above the ground. The space between the four foundation blocks is filled in with gravel covered with a concrete cap so as to prevent the accumulation of ice.

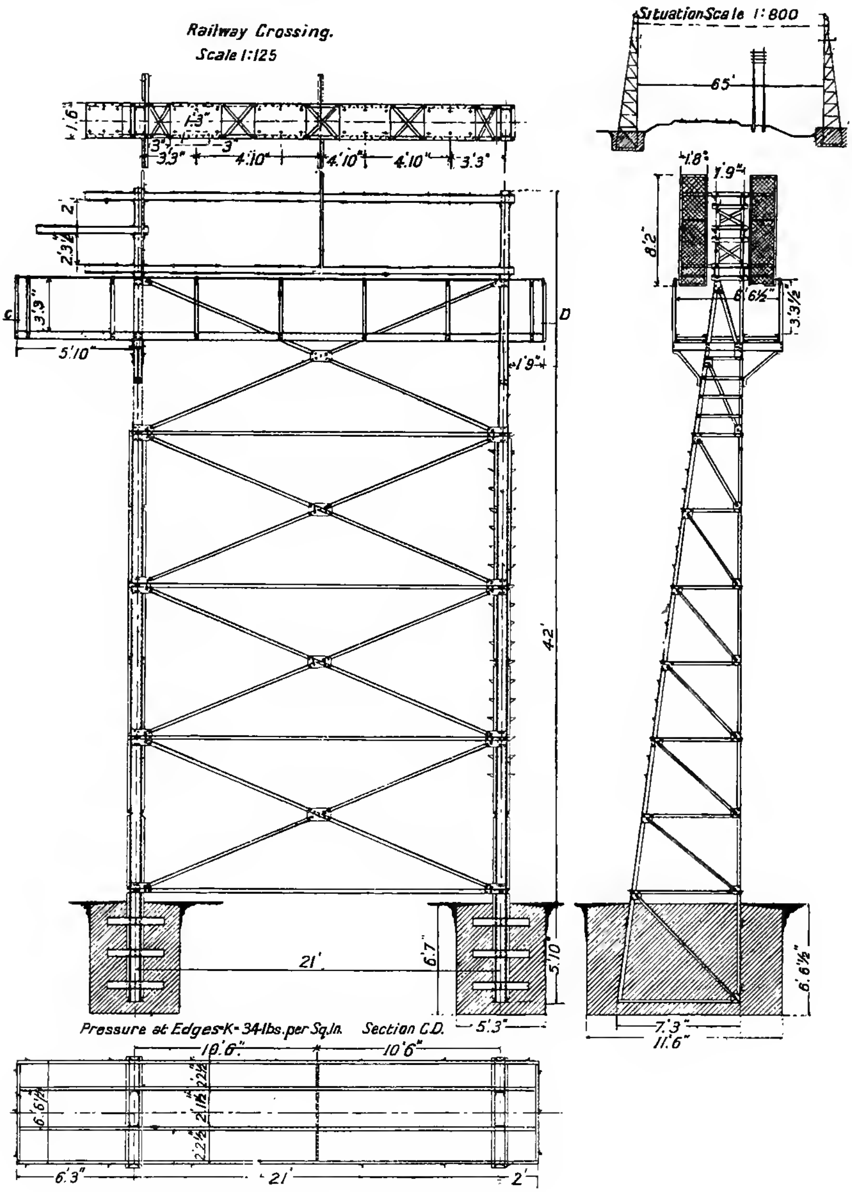


Fig. 107.

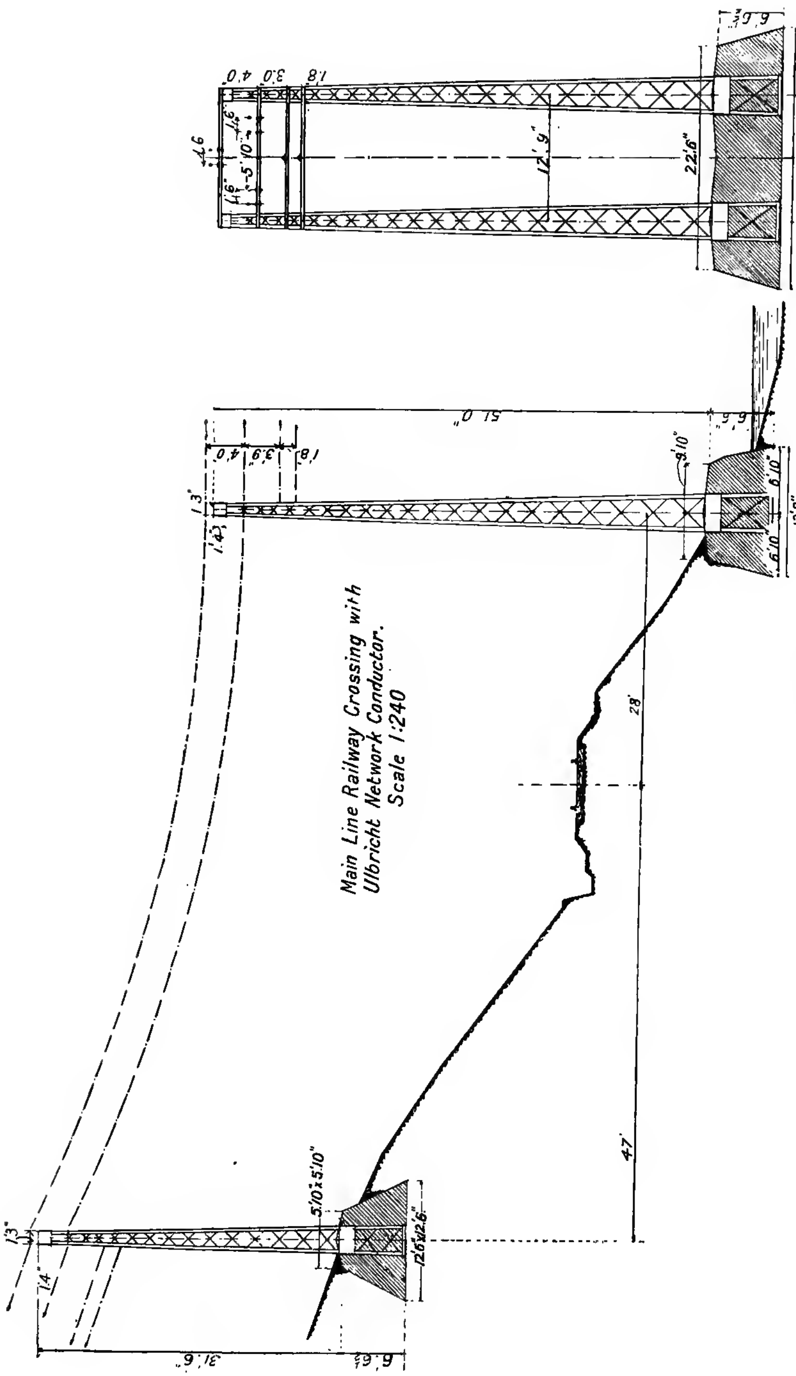
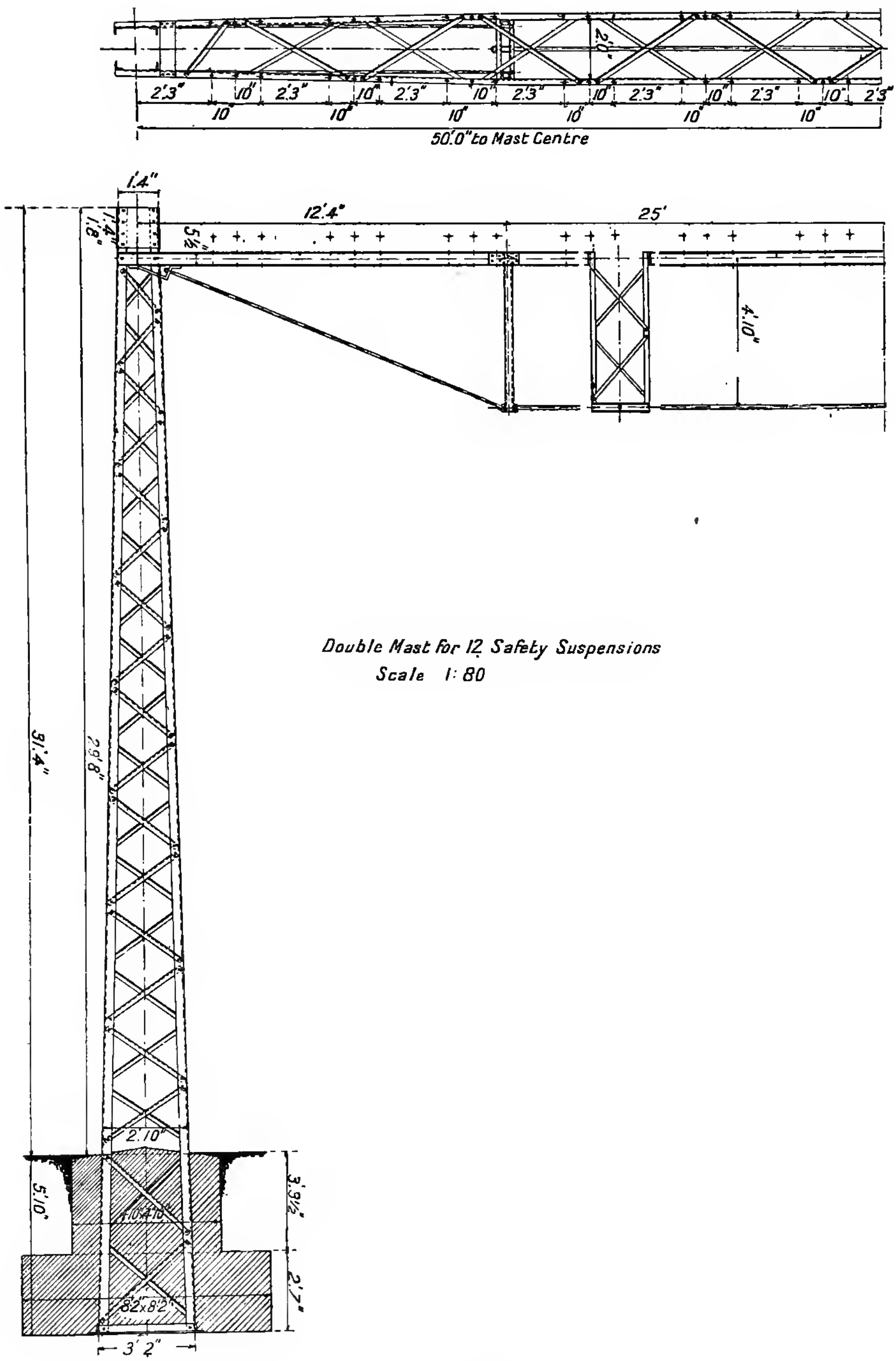

Main Line Railway Crossing with
Ulbricht Network Conductor.
Scale 1:240

Fig. 108.



2'3" 10" 2'3" 10" 2'3" 10" 2'3" 10" 2'3" 10" 2'3" 10" 2'3"
10" 10" 10" 10" 10" 10"
2'0"
50'0" to Mast Centre
1'4"
12'4"
25'
5½"
4'10"
31'4"
29'8"
2'10"
5'10"
3'9½"
2'7"
3' 2"
Double Mast for 12 Safety Suspensions
Scale 1: 80

Fig. 109.

The mast shown in Fig. 103 is provided with a circular platform to give a secure foothold for workmen inspecting or repairing lines or insulators.

The mast is mounted by means of a staggered arrangement of iron projections.

Similar structures supplied to the Allgemeine Elektrizitäts Gesellschaft of Berlin are shown in Figs. 104 and 105. One of these is used at a crossing of the Oder at Schiffsmühle and since the ground was not firm enough it was mounted on piles as shown in Fig. 104. These masts are provided with hinged feet, so that the mast can be completed on the ground and can then be raised bodily into its vertical position.

Fig. 106 shows a H.T. line crossing a road with telegraph wires by means of a special safety bridge structure. The free spans are kept very short and the mechanical stresses very low. The tensions of the line spans on both sides of the crossing are taken up by the towers.

Fig. 107 shows a railway crossing arrangement. Here the masts are provided with an inspection platform and the various circuits are separated from one another by safety screens.

Fig. 108 shows an application of Ullbrichts' network conductor for crossing a railway line. In this case double masts are used at each side of the crossing. Another double mast arrangement is shown in Fig. 109.

The methods adopted for securing masts to their foundatio .s by means of foundation bolts are indicated in Figs. 110 and 111. The safety screens used for separating the various circuits on a mast are also shown. These make it possible for repair work to be carried out without danger on one of the circuits (after making it dead) without interfering with the second high-tension circuit.

The round iron rings shown at the tops of these masts are intended as perches for the larger birds to settle on in preference to the wires.

Figs. 112 and 113 show two forms of mast and cross-arms as used with suspension insulators. The large space occupied by the bases of the towers in these cases make them only suitable for use on land of low value.

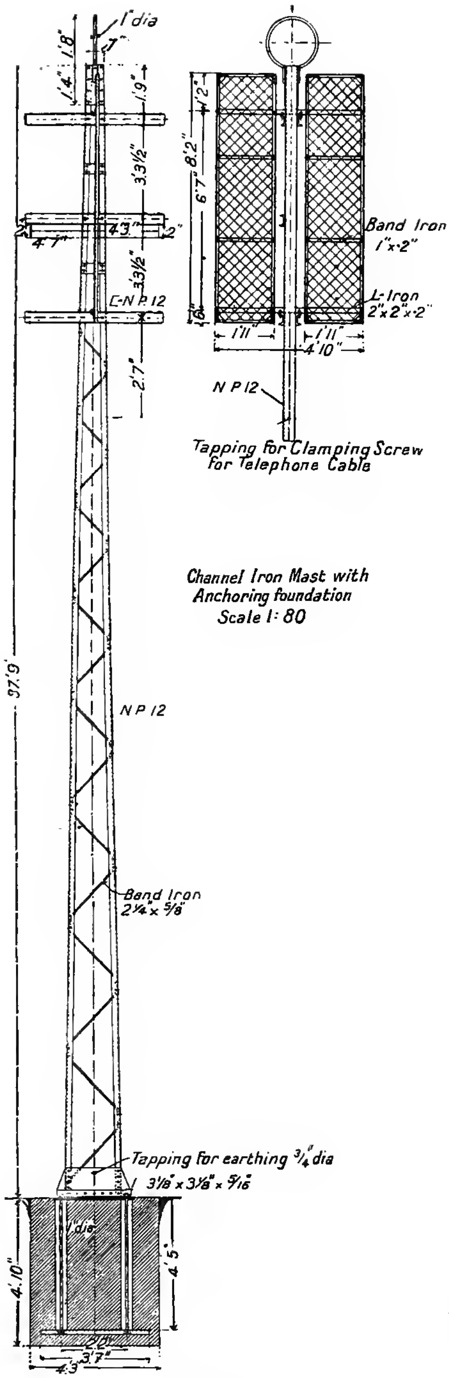


Fig. 110.

10. OVERHEAD LINE INSULATORS.

Insulators are practically always made of "hard" porcelain, whose chief constituent is kaolin, to which are added small quantities of quartz and felspar. The glazing consists of a mixture of kaolin and silica.

A freshly-broken porcelain insulator should show a light speckly fracture and must not be porous.

Glass insulators were at one time commonly used in France and, for low voltages, in America, but their brittleness and inability to withstand the weather conditions have practically led to their disappearance from transmission work. An attempt has also been made to combine the high breakdown voltage of glass with the weather-resisting powers of porcelain by making up combination insulators whose outer part is of porcelain and inner portion of glass. At the present time, however, the porcelain insulator is practically without competitor.

A good insulator should, in the first place, show a high piercing voltage. The thickness of porcelain necessary for mechanical safety makes this condition easily attainable. The actual piercing of an insulator is likely to cause far more serious damage than a mere surface discharge, as the latter will generally only cause the opening of a circuit breaker.

The second condition to be fulfilled is that of a high surface discharge voltage with the insulator damp or wet. The voltage required to cause a surface discharge must be high enough to prevent breakdown occurring under ordinary conditions

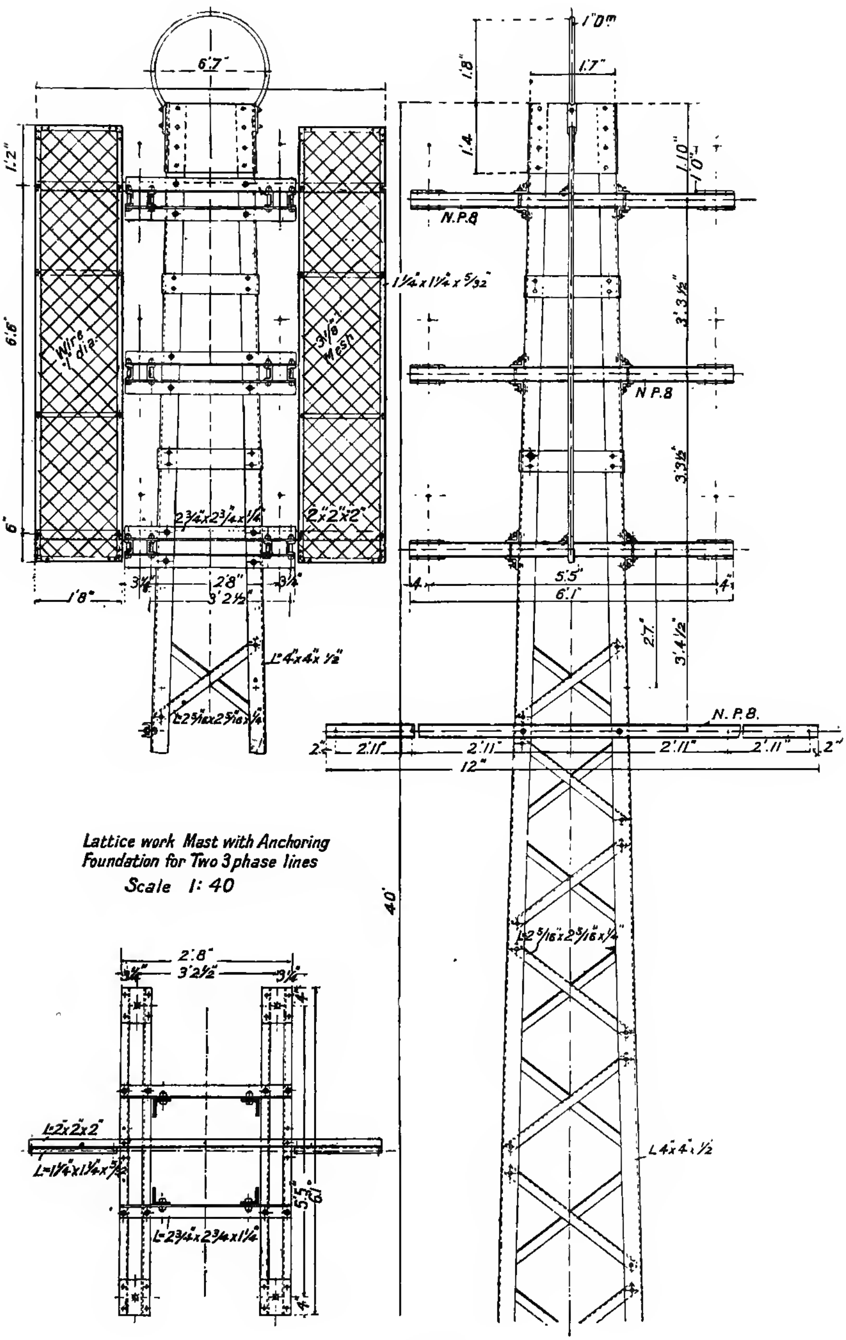
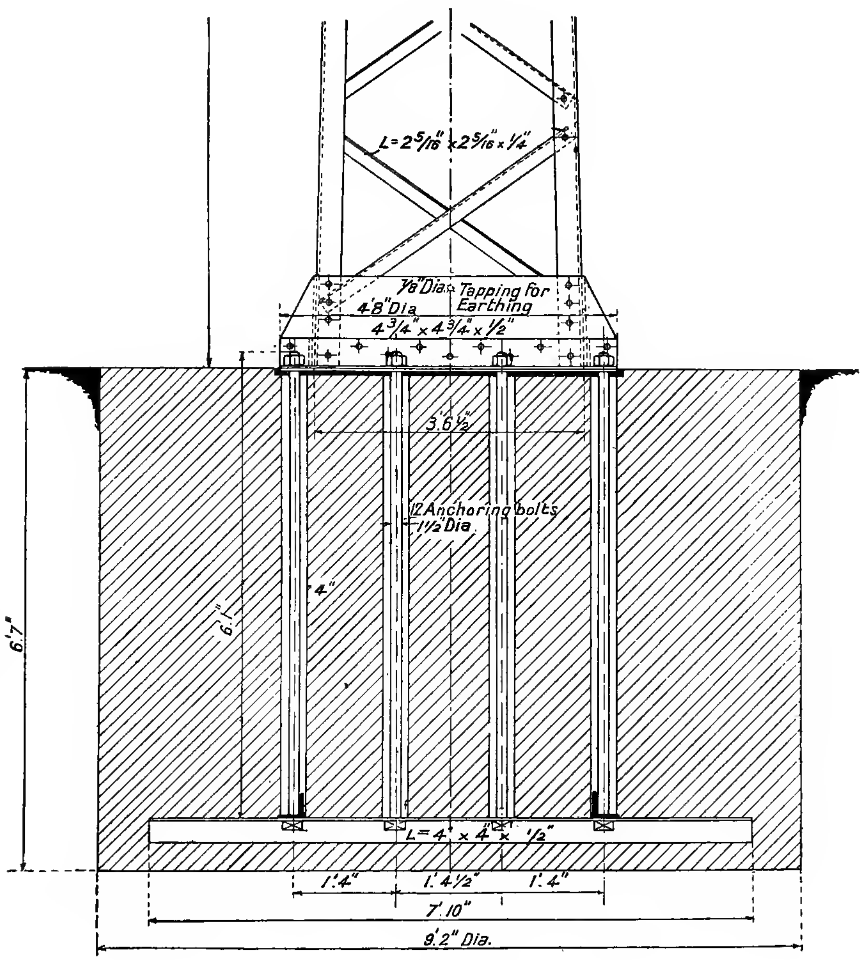

Lattice work Mast with Anchoring
Foundation for Two 3 phase lines
Scale 1: 40
N.P.8
N.P.8
N.P.8.
40'
L 4"x 4"x ½"

Fig. 111.

of voltage rise, such as may take place through switching operations, atmospheric effects, earthing of one of the wires (thus throwing the full line-to-line voltage on the insulatoı), etc.

All insulators should have a high surface insulation resistance so as to minimise the leakage losses and to avoid trouble with neighbouring postal lines. This can be attained by suitably dimensioning the insulator, and a margin should be allowed so that in case of slight damage sufficient insulating power remains to avoid a complete breakdown before the insulator can be replaced.

Besides these electrical properties the insulator must also be able to withstand the vertical and horizontal mechanical forces due to the line. The vertical downward pressure due to the weight of the line is small compared with the horizontal force due to the line tension. The insulator must have at least as great a



Formulation to Fig. 111.

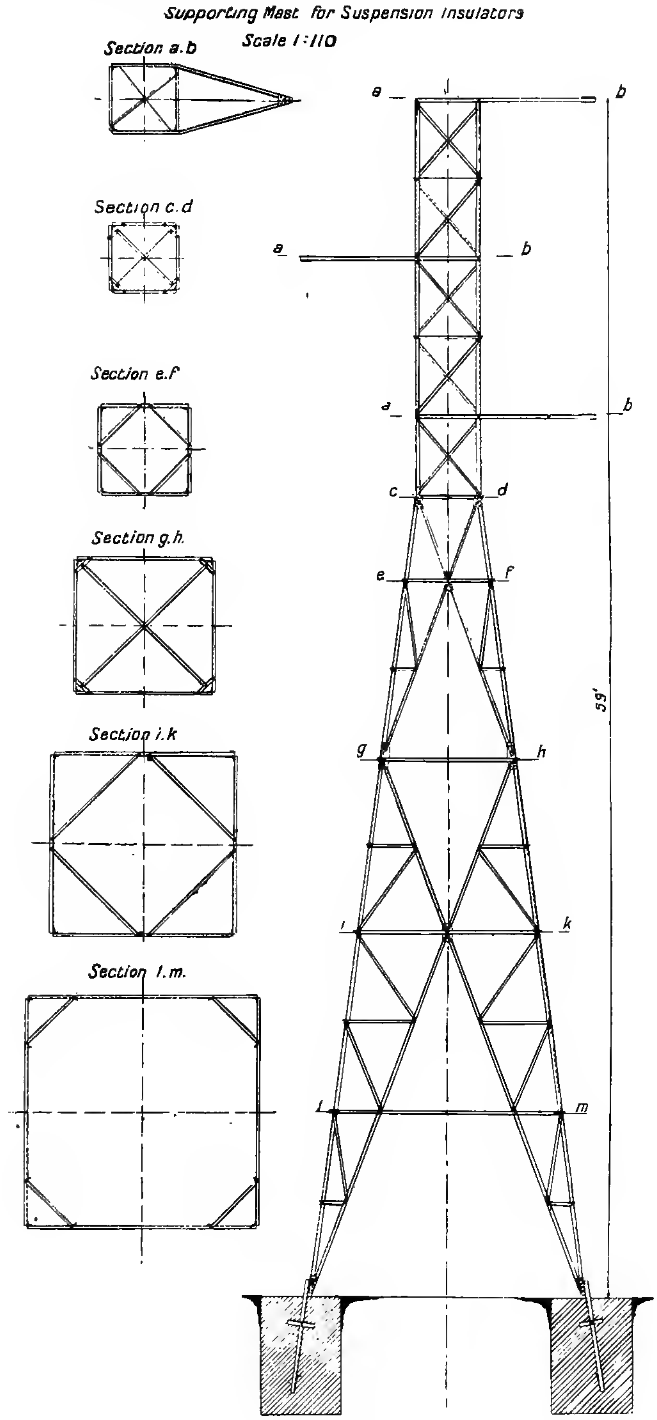
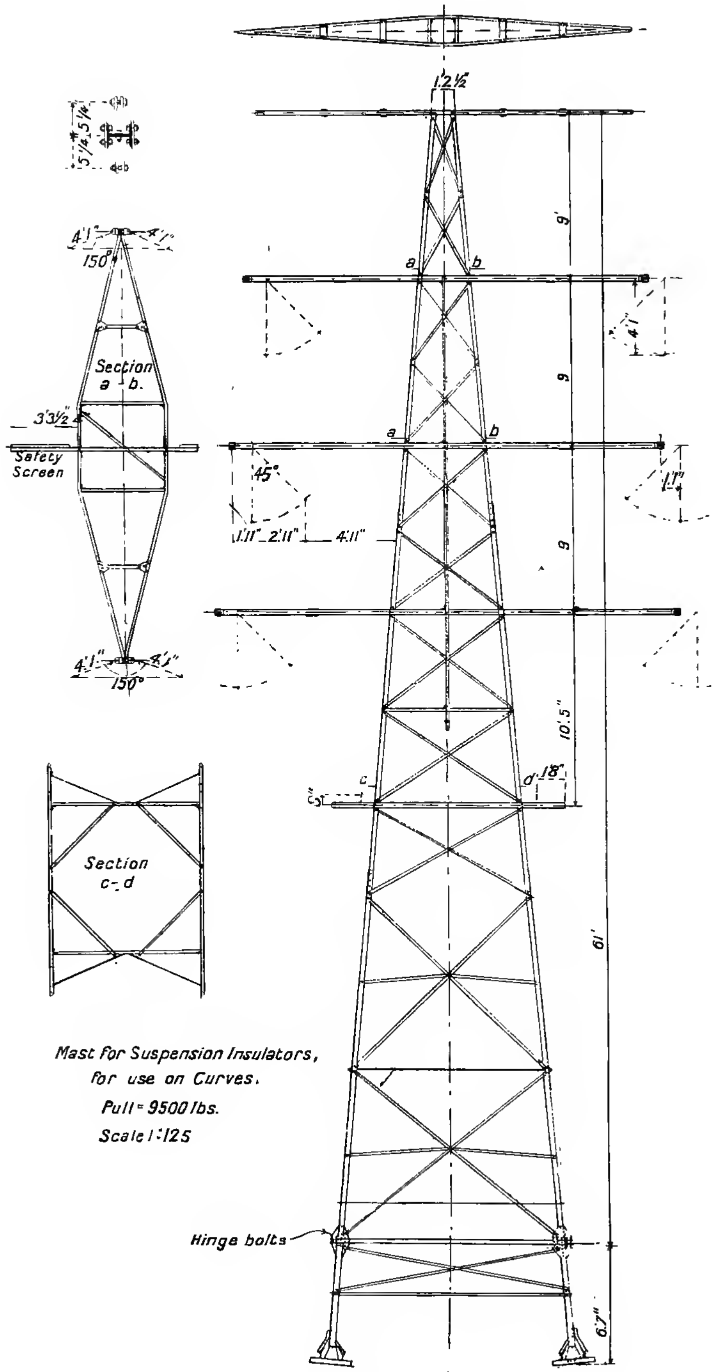

Supporting Mast for Suspension Insulators
Scale 1:110
Section a.b
Section c.d
Section e.f
Section g.h.
Section i.k
Section l.m.
a
b
c
d
e
f
g
h
i
k
l
m
59'

Fig. 112.



Section
a b.
Safety
Screen
Section
c-d
Mast for Suspension Insulators,
for use on Curves.
Pull = 9500 lbs.
Scale 1:125
Hinge bolts

Fig. 113.

factor of safety, under the most extreme temperature conditions, as the rest of the structure.

Often mechanical breakdown does not occur directly through failure of the insulator itself, but indirectly through bending of the pin. This results in the pin bearing hard against the lower portion of the porcelain thread and eventually causing fracture. It is therefore advisable to use pins of ample dimensions.

Experience has shown that trouble with insulators, especially in industrial districts, has most often been caused by smoke or soot deposits and sometimes, in the case of coast lines, by salt deposits.

As regular cleaning of the insulators is generally out of the question, their shape must be such that the rain itself serves, at least partially, to keep the surfaces clear.

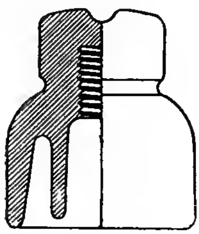


Fig. 114.

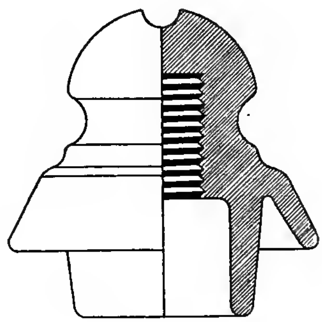


Fig. 115.

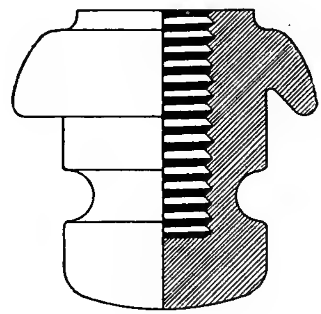


Fig. 116.

The surface of the insulator must be entirely unaffected by the acids which are present in the atmosphere. In the case of glass, at least, deterioration has been found to occur from this cause. Further, the surface of the insulator must not be damaged by brush discharges or their accompanying phenomena. Ebonite is unsuitable on this account because it is slowly attacked by ozone. Ambroin insulators also have to be protected against brush discharges by means of porcelain caps. Glass, owing to its brittleness, is easily fractured when a temporary discharge occurs.

For economy and ease in erection it is essential that the whole design of the insulator shall be as robust as possible. Thin rims are easily broken in transport. Very flat tops are objectionable, as the line wire is liable to be bent into contact with them. The insulator should, further, be more or less self-protective against falling boughs, stone throwing, etc.

All these points imply a massively-built insulator, but, on the other hand, considerations of cost and charges for transport and for erection make it desirable to keep the insulator as light as possible. These latter considerations are especially important in connection with the very large insulators used for the highest voltage transmissions.

The impossibility of building high-voltage insulators sufficiently light has, in fact, largely extended the use of the suspension type of insulator described below.

Finally it should be pointed out that the insulators should have as open

a shape as possible, for narrow, dark openings are liable to be taken possession of by insects, which will in time completely fill them with their webs and excretions.

The earliest power circuit insulators were developed from the existing telegraph insulators, of which the first double-petticoat type (Fig. 114) was introduced by Chauvin in 1858. This type is still much used for low-voltage installations and occasionally also for high-voltage schemes up to 3,000 volts. Fig. 115 shows an insulator especially suitable for low-voltage work. Fig. 116 shows the same type carried out as an inverted (or suspension) insulator.

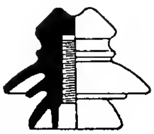


Fig. 117.

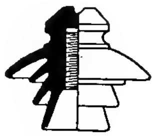


Fig. 118.

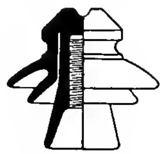


Fig. 119.


Fig. 120.

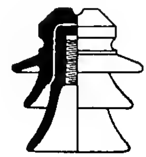


Fig. 121.

For voltages over 3,000 the double-petticoat type was enlarged into the triple-petticoat type, which ten or fifteen years ago was a great favourite for voltages up to 6,000. As far as mechanical considerations are concerned this type meets all requirements, but it does not offer much resistance to surface or rim discharges because of the short distance between pin and outer rim. Some improvement was effected by increasing the outer diameter through the addition of a cover outside the existing cylindrical mantle. The limit was soon reached, however, through the excessive weight and size required and the difficulty of getting sound porcelain, free from cracks and blow-holes, in these large sizes.


Fig. 122.

A fundamental change was introduced in 1897, in the form of the Delta insulator, by the Hermsdorf Porcelain Company. This type gave greatly improved security against surface (brush) discharges. Fig. 117 shows the original form, in which it was widely used. Figs. 118 to 121 show the way in which experiment and experience led to its gradual development into its present form. The net result has been the attainment of an increased flash-over voltage without increased weight of porcelain.


Fig. 123.

Table 26 contains some particulars of the most commonly used Delta insulators of the Hermsdorf Company. The type with wide pin opening is intended for use on strain masts and corner masts, where the pin has to be of large diameter to withstand the heavy pulls.

Fig. 122 shows an insulator made by Ph. Rosenthal & Co., of Selb, in which the middle petticoat is replaced by a number of shorter mantles or ribs. Fig. 123 shows the same makers' "Kammerisolator." Table 27 gives particulars of these two types.

TABLE 26.

Working Voltage.	Type J, with narrow Pin opening.	Net weight in lbs.	Type J, with wide Pin opening.	Net weight in lbs.	Height of Line Wire above the Cross-arm (inches).
8,000	1,381	1·45	—	—	5
10,000	1,382	2	—	—	7·5
15,000	1,383	2·85	1,402	2·9	5·75
20,000	1,384	3·75	1,403	4·2	6·75
23,000	1,385	5·1	1,404	5·3	7·5
27,000	1,386	6·2	1,405	6·7	8·75
30,000	1,387	7·5	1,406	8·2	9·5
33,000	1,388	9·7	1,407	10	11
37,000	1,389	11·2	1,408	12	12
40,000	1,390	12	1,409	14	13·5
43,000	1,391	14·5	1,410	16·5	14·5
48,000	1,392	16·5	1,411	19	15·5
50,000	1,393	20	1,412	22·2	17
53,000	1,394	22·2	1,413	24·5	18
56,000	1,395	26·5	1,414	30	19
60,000	1,396	29	1,415	32·5	20

It was explained above that the use of large masses of porcelain led to the presence of cracks, etc. This trouble can be partly overcome by careful design, but for voltages above about 20,000 it becomes necessary to make up the insulator in two parts in order to ensure sound results. The two parts may be either

TABLE 27.

Working Voltage.	Ribbed Insulator.		Kammerer Insulator.		Test Voltage of the whole Insulator and of the Component Parts.
	No.	Weight (lbs.).	No.	Weight (lbs.).	
5,000	901	·67	1,001	·74	25,000
8,000	902	·84	1,002	·95	32,000
10,000	903	1·42	1,003	1·38	40,000
12,000	904	1·95	1,004	2	45,000
15,000	905	3	1,005	3·2	56,000
20,000	906	3·9	1,006	4·4	66,000
25,000	907	4·9	1,007	5·5	80,000
30,000	908	7	1,008	7·8	85,000
32,000	909	8·4	1,009	9·6	45,000 and 45,000
37,000	910	9·7	1,010	12·4	50,000 ,, 50,000
40,000	911	12·7	1,011	13·8	50,000 ,, 50,000
45,000	—	—	1,012	17	55,000 ,, 55,000
50,000	—	—	1,013	20·5	60,000 ,, 60,000

furnaced together, *i.e.*, combined into one piece in the oven, or they can be finished off quite separately and be subsequently cemented together. In the case of three-part insulators a combination of both processes is often used.

All the insulators dealt with up to the present, although differing widely in form, have one thing in common, viz., the rapid increase in weight with increasing voltage. Thus the insulator No. J1,384, for 20,000 volts, weighs only 3·75 lbs., whilst J1,396, for 60,000 volts, weighs 29 lbs. Trebling the voltage has increased the weight nearly eight-fold. This fact has made it necessary to develop another form of construction altogether, especially for the higher voltages over 60,000 or 70,000. It was for this purpose that the so-called " suspension insulators " were introduced, being probably developments of the old strain insulators. The characteristic point about them is that the line wire is carried below the suspension point and that this enables a number of independent insulators to be used in series in place of a single large pin insulator.

Owing to the improved arrangement of the surface the leakage from suspension insulators is often only half as great as for the corresponding pin insulator. Also the piercing voltage of a group of suspension insulators is at least as great as that of a multi-part pin insulator, and it can be increased at will by adding more units to the string of suspension insulators. The greatest improvement, however, is the reduced tendency to brush discharges, which appear at comparatively low voltages with pin insulators because of the surface creepage.

Another important advantage of suspension insulators is the comparatively small stock of separate designs which is required to meet all cases. With pin insulators, on the other hand, several types and sizes are generally wanted on each scheme. With the suspension type it is practically only necessary to vary the length of the chain of insulators. The separate units are comparatively small and easy to manufacture with great uniformity. This results in economy with regard to stock carried, time of delivery, reliability, etc.

The possibility of raising the voltage of an installation without scrapping the existing insulators is another advantage possessed by suspension insulators. It is only necessary to add one or two units to each chain to satisfy all the requirements of the higher voltage. If pin insulators were used it would be necessary to employ specially large and expensive insulators from the first if a complete change is not to be required when the voltage is raised at a later date.

Even where an increase in voltage is not contemplated, it is often a great convenience to be able to increase the margin of safety of the insulation at certain parts of a line (*e.g.*, near the sea coast, in industrial districts or across fen or marsh land) as experience accumulates. The ease in mounting and in replacing suspension insulators as compared with pin insulators is a further advantage not to be underestimated. In case of damage, instead of having to replace a whole expensive pin insulator it is only necessary to replace the particular unit of a suspension insulator which is the cause of the trouble. The risk of serious damage, for instance through stone-throwing, is reduced to a minimum, as the probability is that only one unit will be damaged and the remainder of the chain of suspension insulators will usually be able to prevent an interruption of the supply.

The actual shape of the suspension insulators is as varied as with pin insulators. Some shapes are extremely simple, consisting merely of a single flat or corrugated saucer; others are of complicated shape, and sometimes are made up of two or more parts. Two fundamental types, however, can be distinguished. In the one the iron connections are linked together in the form of a chain only separated by the body of the insulator (Fig. 124), and in the other the upper and lower metal parts of an insulator embrace one another cylindrically with the

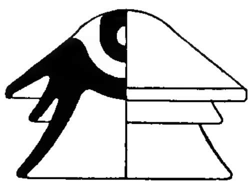


Fig. 124.

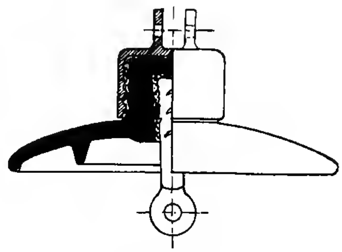


Fig. 125.

porcelain between, but are not actually linked through one another (Fig. 125). In the former arrangement the porcelain is chiefly in compression, and should a break occur in the porcelain the iron parts still remain linked and mechanically useful in preventing the line from falling. In the second type, if carefully shaped, the porcelain can also be subjected to compressive stress, or at least shearing stress, but, should a breakage occur, the risk of the line falling is considerable. The great

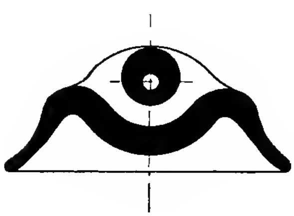


Fig. 126.

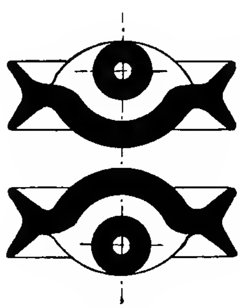


Fig. 127.

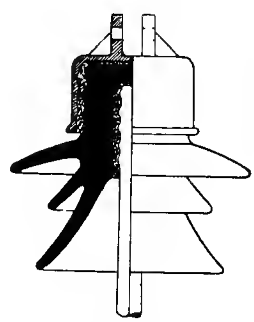


Fig. 128.

mechanical strength of this type, however, makes breakage unlikely, whilst at the same time it possesses certain marked advantages over the linked type from the electrical point of view.

Of the linked patterns, the best known and the one most commonly used in America is that shown in Fig. 126, due to Hewlett. When used for straining purposes, *i.e.*, in a horizontal position, the shape is somewhat modified, as shown in Fig. 127, so as to make both sides symmetrical.

Recently the channels in the chain form of suspension insulator have been

given a square bore in place of a circular one and have been sharply curved at the top. This allows metal strip in place of wire rope to be used for the connections. These metal bands are much more conveniently joined than wire rope by means of screws, etc. Rope, in fact, requires the use of special clips unless thin rope is used and is wound through the insulator time after time, in which case the resulting friction gives sufficient grip.

Fig. 128 shows a suspension insulator of the Delta type made by the Porzellanfabrik Hermsdorf, which has been used on a number of power schemes. Its size is such that each unit can stand about 25,000 volts. For 50,000-volt circuits, therefore, two units are used in series and for 70,000 volts three.

Fig. 129.

Fig. 129 shows a suspension insulator made by the Porzellanfabrik Rosenthal. The same firm's strain insulator as used on the 110,000-volt power scheme of the Lauchhammerhütte is shown in Fig. 130. Fig. 131 shows a strain mast fitted with these insulators.

On straight stretches the suspension insulator meets all the mechanical demands, but at corner points, where a sideway pull has to be taken up, their flexible nature makes somewhat special arrangements necessary. These side pulls sometimes subject the insulator to heavy stresses, and to meet these such strain insulators are often given an additional $\frac{1}{2}$ or $\frac{3}{4}$ inch in depth. The breaking load is in this way raised to about 14,000 lbs. For specially heavy loads still greater depths are sometimes employed.

The mechanical safety of the installation is increased when suspension insulators are used, as their flexibility enables equalisation of stresses to take place both on straight stretches and at corners. Should a line breakage occur on one side of a mast the latter will not be subjected to much stress, as the chain of insulators will set itself in a slanting direction and virtually lengthen the line, thus relieving the tension in it. The mechanical and electrical protection against damage through lightning is enhanced when suspension insulators are used because the earthed mast and cross-arms project well above the lines. This fact goes a long way towards paying for the somewhat increased height of mast required with suspension insulators. With pin insulators the same protection has to be sought by running an earthed wire rope over the line.

Another mode of protection against lightning or other discharges to the insulator supports is offered by the use of the guard ring introduced by the Por-

zellanfabrik Hentschel and Müller (Figs. 132—134). This metal protective ring is intended to take the discharge direct from the line to earth without its touching the insulator or, at any rate, only touching the upper surface. Should a

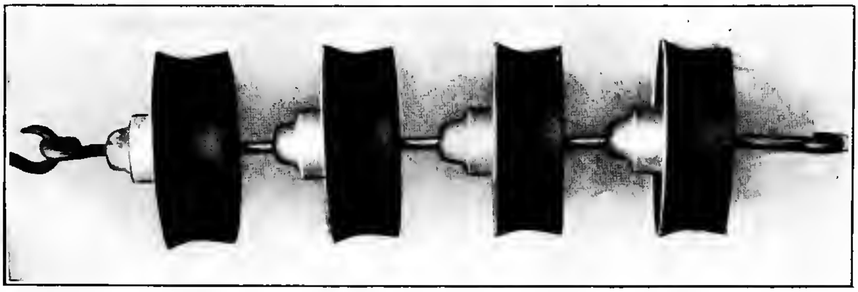


Fig. 130.

discharge occur over the surface of the insulator the well-known outward tendency of the arc will soon cause it to jump across to the guard-ring. Such a ring reduces the breakdown voltage of the insulator in the dry state, but does not affect the wet state breakdown voltage.

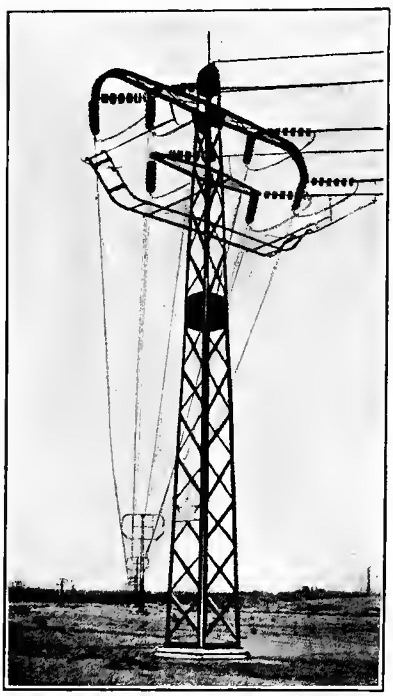


Fig. 131.

The Niagara, Lockport and Ontario Power Company has carried out extensive experiments with these guard-rings on a H.T. line. Half of a 375 mile line was fitted with guard-ring insulators and the other half with ordinary ones. The result was that, in a given period, of the protected insulators only one was entirely destroyed and 13 others were somewhat damaged, but not enough to put them out of action. The corresponding figures for the unprotected insulators were 54 and 36 respectively. It was found that four times as many of the insulators at the top of the masts broke down as of insulators mounted on the cross-arms. The protective ring can be either made of wire netting or of band iron. If made of narrow mesh netting or of perforated sheet it also serves as a partial protection against stone-throwing.

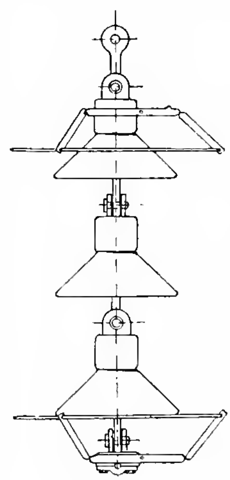


Fig. 132.

Fig. 133 shows clearly how the arc in the case of a ring-protected Delta insulator passes direct from the line to the ring without touching the inner mantles. Fig. 134 shows the action when protective rings are fitted both at the top and the

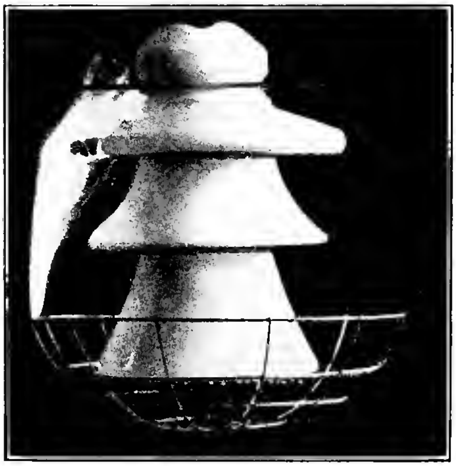


Fig. 133.

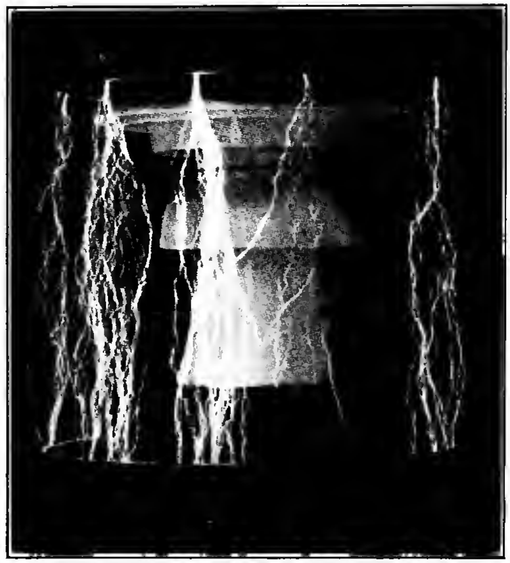


Fig. 134.

Fig. 135.

bottom. The air gap between the two rings is bridged without the arc touching the insulator. Fig. 135 shows the breakdown of the same insulator without protective rings.

11. ATTACHMENT OF THE INSULATORS TO THEIR PINS.

INSULATORS are attached to their pins in a great variety of ways. All sorts of cements for the purpose have been put on the market, some of which are unsatisfactory because they attack the pin chemically and others because their coefficient of expansion differs from that of porcelain. A good method consists in the employment of hemp soaked in linseed oil or in red-lead. The mounting however, requires training, skill, and reliability, and it is not advisable, therefore, to leave it to unskilled labourers to fill in their time on. The safest plan is to obtain the insulators ready mounted on their pins from the porcelain factory. The Porzellanfabrik Hermsdorf state that a great many insulator defects which they have investigated have turned out to be due to faulty mounting and the use of unsuitable materials for it. They have therefore circulated the following instructions.

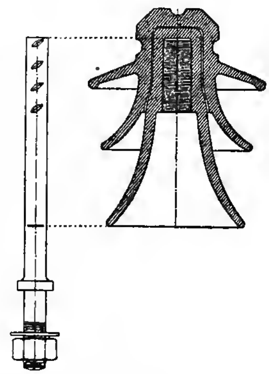


Fig. 136.

In the first place mark the point on the pin to which the lowest mantle reaches when the pin is screwed home (Fig. 136). Next fix the pin in a vice and wrap the thread round with selected long-stranded hemp, covering the end of the pin as well. The prepared end should be of approximately the same diameter and length as the threaded hole in the insulator. The hemp is then to be smoothed over by hand or by a special tool and to be painted with linseed oil or red-lead. Before screwing the pin in a small pad of felt, leather, or asbestos should be placed on the floor of the hole. The pin can then be screwed home. The mark previously made on the pin will serve to prevent excessive tightening of the screw and cracking of the insulator, but, in order to make quite sure that no undue stresses have been set up, it is advisable to unscrew the pin slightly again after it has been screwed home.

Special machines for ensuring rapidity and uniformity in mounting insulators have been devised. One such arrangement, for instance, is used to compress and smooth the hemp pad on the pin. The hemp-covered pin is turned by hand whilst being at the same time pressed into a trough-shaped recess. When ready the pin is held in a vice and the insulator is screwed on to it by means of a second tool on the principle of a band brake, which enables a secure hold to be got of the insulator, and is especially useful for large sizes.

The screwing on of large insulators is, however, always a delicate matter, and greatly dependent for good results on the conscientiousness of the workman. On this account the use of cement for fixing the pin has been largely resorted to in America with very satisfactory results. With the best cement carefully prepared

there is little danger of cracking, but it is always advisable to introduce a layer of compressible material between the pin and the porcelain so as to admit of the cement expanding and contracting. A thin felt sheath is suitable for this purpose, and experiments carried out under the authors' direction on insulators prepared in this way have shown quite satisfactory results over long periods and with the widest temperature variations.

It has often been stated that one advantage of the hemp fixing is that the insulator can be replaced in case of accident without removing the pin from the cross-arm. This is a mistake, however, as the conditions existing when repair work is going on (storms, want of time, awkward position on the mast, etc.) prevent the remounting being properly carried out. It is always preferable to take the new, ready-mounted insulator to the mast and to replace the complete pin and insulator. All pins should, therefore, be provided with hexagon or flatted grips to facilitate unbolting with a spanner.

Suspension insulators of the bolt and cap type (Fig. 125) must be so arranged that the expansive force of the Portland cement used to fix the bolt and the cap cannot damage the porcelain. This can be effected by making the cemented bolt lie within the tempered steel outer cap, which then takes up the expansive force and prevents damage.

12. ATTACHMENT OF THE WIRE TO THE INSULATOR.

In the case of pin insulators the wire can be carried either in a recess at the top of the insulator or in the neck groove. At bends and corners the wire should be laid in the neck groove in such a way that the line is forced against the side of the porcelain by the line tension, the insulator lying within the angle formed by the line. On straight stretches of line the use of the top groove, or of a recess in a special cap carried at the top of the insulator, is preferable to the side groove.

The binding or tying-in arrangement between line and insulator is subjected to—(1) the weight of the line, (2) the wind pressure on it, and (3) any difference in line tension which may exist on the two sides, and consequently must be very carefully carried out. Objectionable interruptions of supply through falling wires have often been caused by insufficient binding. By using the top groove to carry the wire the effect of the line weight and the wind pressure is removed from the binding wire, and the latter has only to counteract the net longitudinal tension. The line weight falls directly on the insulator, and the wind pressure is taken up by the sides of the groove. By suitably shaping the groove all necessary security against blowing down can be ensured. The top groove support has one disadvantage in that the wire is liable to rub against the edges of the recess. Trouble from this cause can, however, be avoided by slipping a split metal tube over the wire or by winding a spiral of metal ribbon round it at the insulator (see Fig. 141). The line wire must be fastened to the insulator in order to prevent longitudinal motion, which would in time damage both the wire and the insulator. Unbalanced longitudinal tensions can be set up in a line as a consequence of unequal span lengths (temperature changes) on the two sides of an insulator, unequal snow or ice deposits, the settling of birds (swallows, starlings, etc.), or through unequal wind pressures, and are sometimes quite considerable. Large line wires are, therefore, now generally securely attached to the insulators by means of special caps and clamps.

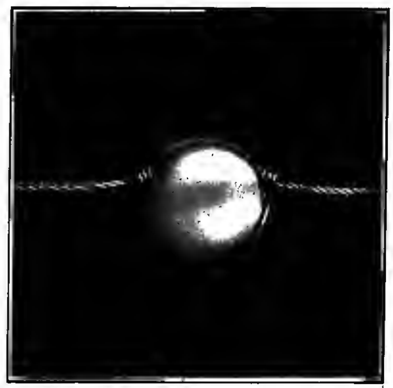


Fig. 137.

When making a tie care must be taken to avoid kinking the main wire by means of the binding wire. The old, simple arrangement shown in Fig. 137 is now seldom used because of the way in which it bends the line and tends to damage it. Care must also be taken not to nick either the line wire or the binding wire with the pliers when making the tie. The material used for the binding wire can be soft copper for short spans and local distributing networks generally. In other cases

Fig. 138A.

Fig. 138B.

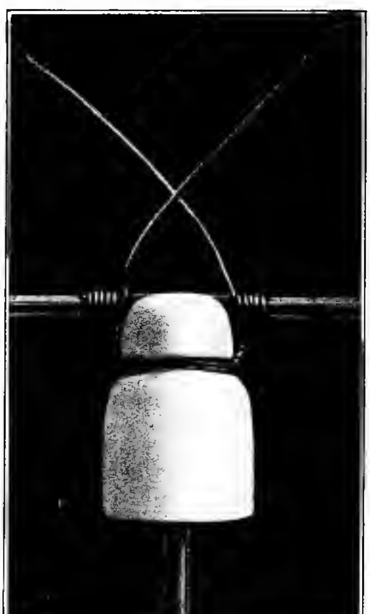


Fig. 138C.

medium hard drawn copper should be used. For line wires between ·14 and ·22 inch in diameter a binding wire of from ·09 to ·11 inch in diameter should be used, whilst for larger lines the binding wire should be ·11 to ·14 inch in diameter. Copper-clad steel forms a good binding wire and, owing to its strength, a somewhat smaller diameter than the above can be used. This is also suitable for tying aluminium lines, the soft metal being protected by means of a tube or a spiral band at the tying point. The binding should be done by hand without the use of pliers.

In order to avoid waste it is advisable to supply the wiremen with the binding wire in ready-cut lengths, the correct length being first determined by trial in the following way :—

When the Top Groove is used.—Two binding wires are wound round the insulator in opposite directions and in such a way that their two ends are of unequal length (Fig. 138A). The two ends of each wire are then twisted together until the

twisted portion reaches to the bottom of the groove when bent upwards (Fig. 138B). Of the four wire ends thus left the two short ones are now given four or five twists round the line conductor on opposite sides of the insulator (Fig. 138C). Each of

Fig. 138D.

Fig. 138E.

the long ends is brought right over the insulator and then also twisted four or five times round the line wire (Figs. 138D, 138E).

When the Neck Groove is used.—In this case a single binding wire is required, which is carried round the neck of the insulator, starting with the middle of the

Fig. 139.

Fig. 140.

wire, and its two ends are then twisted round the line wire—one from above downwards and the other from below upwards. The ends are then brought forward and both are carried once more round the insulator and line wire, crossing the starting point and finishing off with six or eight twists round the line wire on both sides of the insulator (Fig. 139).

Another method of tying a line into the top groove is shown in Fig. 140. This is the method used on the 60,000-volt line of the Ontario Power Company. The long twisted portions are here intended to add to the section of the conductor (aluminium) so as to delay its melting through in case an arc should occur.

Still another arrangement is shown in Fig. 141, where the binding wire is replaced by terminal clamps and the line is protected by a metal sheath slipped over it. Figs. 142 and 143 show a terminal clamp arrangement suitable for cases

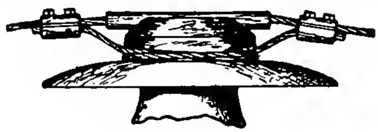


Fig. 141.

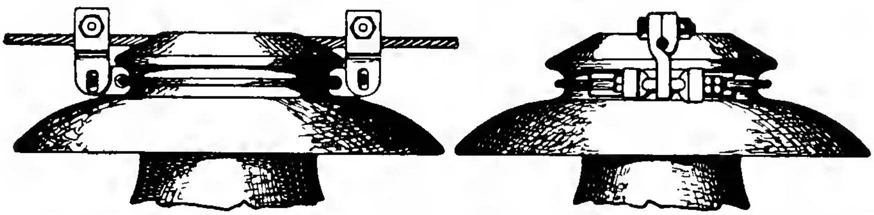


Fig. 142.

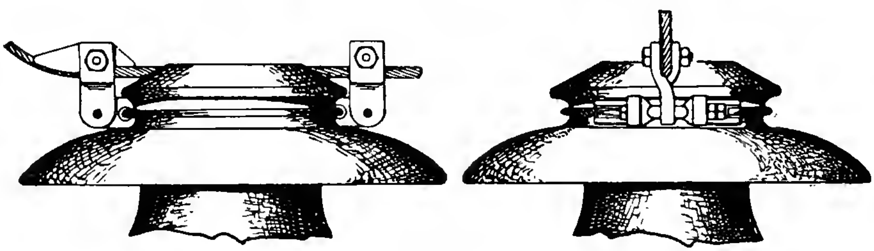


Fig. 143.

in which the line wire slants relatively to the insulator owing to considerable differences in level between the supporting points.

The odd bits of wire cut off during binding operations must be carefully collected as they form a serious danger to cattle by becoming mixed with their fodder or by running into their feet. The longer pieces of wire also are favourite missiles for boys to sling over the line and are then liable to cause short circuits.

In the case of suspension insulators the line wire is carried in a clamp cemented into the first member of the insulator chain as shown in Fig. 132.

13. JOINTS AND BRANCH CONNECTIONS ON THE LINE.

In all cases in which the presence of a joint weakens the wire mechanically the branch wire must be relieved of all tension. The joint should, whenever possible, have the same strength as the wire, but, in any case, it should have a factor of safety of 2½ considering the actual stress existing on the wire. The making of the joint must not weaken the main conductor, must not produce sharp bends in it, it must be light and simple to make, and must not be affected by variations in tension or by the vibrations of the line. The electrical resistance of the joint should remain permanently at least as low as that of an equal length of the original wire. Soldered joints are allowable on soft copper lines and also, when mechanical stress is removed from the joint, on bronze and medium and hard drawn copper conductors.

The heating reduces the strength of hard materials some 25 to 35 per cent. Since soft copper is no longer used for transmission lines, the joints usually required, where mechanical stress cannot be avoided, have to be carried out without soldering, at the same time satisfying the above-stated conditions as nearly as possible.

Solid wires up to about ·22 inch in diameter (·04 square inch area) can be connected by means of spiraled metal sheaths (Ard couplings) (Fig. 144). When employed for connecting stranded cables over about ·025 square inch in section these couplings become very long and expensive. They are largely used on stranded aluminium cables and have proved eminently satisfactory. The length of sheath required for various copper and aluminium conductors is given in the following table :

TABLE 28.

Cross-section of Copper in sq. inches.	Length of Sheath in Inches.		Cross-section of Aluminium in sq. inches.	Length of Sheath for Stranded Aluminium Cables in inches.
	Solid Copper Wire.	Stranded Copper Cable.		
·0155	8	—	·039	18
·025	10	18	·054	20
·039	12	23½	·078	22½
·054	14	31½	·108	27½
·078	16	35½	·148	33½
·108	—	40	·186	40
·148	—	43½	·235	43½
·186	—	47	·29	47
—	—	—	·31	49

In making the joint the procedure is as follows :—

After baring and cleaning the wire ends they are placed in a sheath of the correct size (Fig. 144) with a projection of about ½ inch at each side. The ends

Fig. 144.

of the sheath are then gripped by means of special spanners (Fig. 145) and twisted spirally : five or six complete twists are required. The spanners must be placed about an inch from the ends of the sheath in order to avoid splitting the latter. In the case of stranded cables the twisting must be carried out in the same direction as that in which the stranding has been done. The wires twisted together should be free for at least 25 or 30 yards so that the twist can be sufficiently distributed. Fig. 146 shows a finished joint. The twisting is found to affect the strength of the wire deleteriously, as can be seen from the following experiments carried out on hard drawn copper wire cables having a breaking stress of 57,000 lbs. per square inch :—

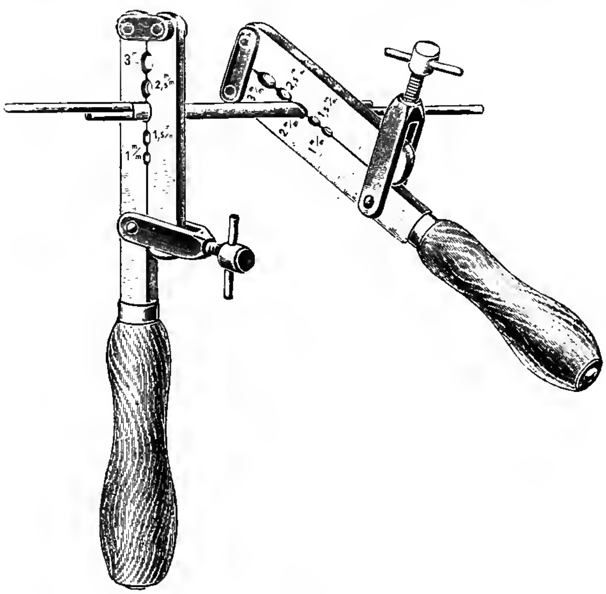


Fig. 145.

TABLE 29.

No. of the Sample.	No. of Wires. In the Cable.	No. of Wires. In the Central Strand.	Diameter of the Wires (inches).	Total Cross-section of Cable (square inches).	Breaking Load (lbs.).	Breaking Stress in lbs. per sq. inch of Cable Cross-section.	Remarks.
25	7	1	·083	·0384	2,030	52,800	In all cases the break occurred in the cable directly against the joint.
35	19	7	·06	·054	2,150	39,800	
50	19	7	·073	·0785	3,830	49,000	
70	19	7	·085	·109	4,830	44,500	

Another satisfactory form of joint, especially suitable for solid wires, is Hofmann's riveted joint (Fig. 147). The bared and cleaned wire ends are placed in the sheath and a conical punch is knocked through the holes in the sheath and forces the wires into the side recesses in the sheath (Fig. 148). Into the openings thus left (Fig. 149) rivets are inserted which keep the wires in position and

Fig. 146.

prevent them being pulled straight again. The subsequent riveting gives a sound and intimate contact between the wires and the inner surface of the sheath. It is essential that the rivet shall force the sheath material flat on to the wire, and this end is best attained by hammering the rivet squarely, and not in such a way as to form the usual head. The inventor of this joint has determined the

Fig. 147.

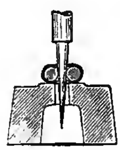


Fig. 148.

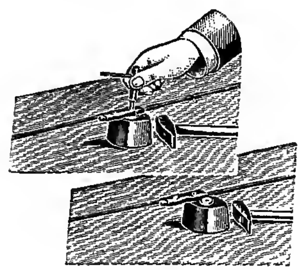


Fig. 149.

exact size of the sheath for each section of wire by experiment, and only this size should be used. This is important, as sometimes the wiremen, finding a difficulty in inserting the wire in the correct sheath owing to burring of the wire ends, have used a larger size of sheath and obtained a poor contact in consequence.

Hofmann also supplies similar junctions for use with stranded cables (Fig. 150).

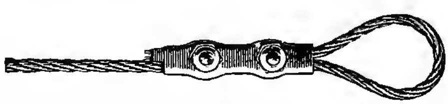


Fig. 150.

In these the rivets are replaced by screws. The making of the joint with these is simple and can be left to unskilled labourers. The material of the conductor, especially if stranded, is somewhat weakened by the driving in of the punch, and by the riveting process and experiment has shown that a copper cable of ·054 square inch section, for instance, having a normal breaking load of 3,100 lbs. breaks at about 2,650 lbs. when it contains one of these riveted junctions. A preferable arrangement for strands of many wires is the conical junction (Figs.

151A and 151B) supplied by the same firm. The component parts of this are shown by Fig. 152. The nuts *a* and *e* are first slipped over the cable ends; the outer layer of wires is then spread out somewhat with a screw-driver and the conical pieces *b* and *d* are slipped over the middle wires of the cable (Fig. 153). The nuts *a* and *e* are then pushed towards the ends of the cable and screwed by hand into the cover *c* as far as possible. Then, by means of a special spanner and an ordinary spanner (Fig. 154), the nuts are tightened up without allowing the

Fig. 151A.

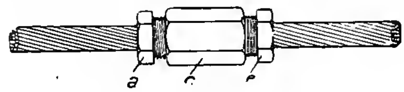


Fig. 151B.

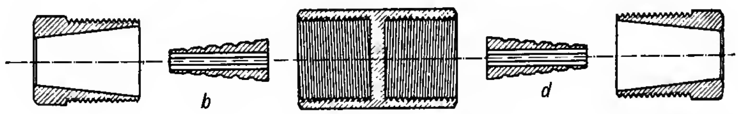


Fig. 152.

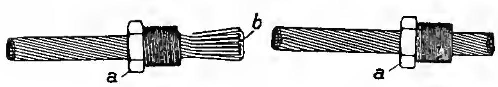


Fig. 153.

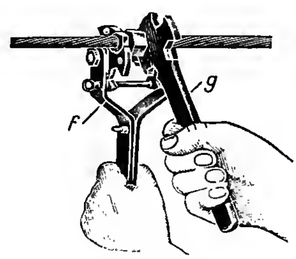


Fig. 154.

cable to turn. The following tables (Tables 30 and 31) show some experimental results on riveted and conical junctions respectively, obtained by the Dresden State Testing Bureaux:

TABLE 30.

No. of Test.	Diameter of the Hard Drawn Copper Wire. (inches).	No. of Rivets in the Joint.	Breaking Load in lbs.	Breaking Stress in lbs. per square inch of Wire Section.	Remarks.
1	·265	3	2,960	54,000	Break occurred in the wire at the joint.
2	·222	3	2,200	56,800	
3	·176	2	1,410	57,000	
4	·142	2	880	55,800	Break occurred in the wir· inside the sheath at the first rivet.
5	·109	2	490	52,500	

TABLE 31.

No. of Test.	No. of Wires. In the Cable.	No. of Wires. In the Central Strand.	Diameter of the Wire (inches).	Total Cross-section of Cable (sq. inches).	Breaking Load (lbs.).	Breaking Stress in lbs. per sq. inch of Cable Section.	Remarks.
25	7	1	·083	·0384	2,200	57,200	Break occurred in wire at the lower clamp.
					2,250	58,400	Break occurred in wire at the upper clamp.
35	19	7	·06	·054	2,930	54,000	Ditto.
					3,000	55,200	Ditto.
50	19	7	·073	·0785	4,000	51,300	7 outer wires broke and then the whole slipped out of clamp.
70	19	7	·085	·109	5,400	54,000	Break occurred in wire at the upper clamp.

Some interesting comparative results for a solid wire, a soldered joint in the same wire, and the same wire joined by one of the riveted sleaves are given in Table 32 :—

TABLE 32.

No. of Test.	Diameter of Wire (inches).	Area of Wire (square inches).	Nature of Test Piece.	Breaking Stress. In lbs. per sq. inch of Wire Section.	Breaking Stress. As a Percentage of that of the Solid Wire.	Remarks.
1	·222	·039	Hard drawn solid copper.	60,300	100	Break occurred at the upper clamp.
2	·222	·039	Ditto with soldered joint.	38,000	63·1	Break occurred in the wire close up to the soldered joint.
3	·222	·039	Ditto with riveted sleave joint.	57,000	94·1	Break occurred in the wire close up to the riveted sleave.

By these results the riveted and conical grip joints are shown to be practically as strong as the original wire. It must be remembered, however, that in these cases the joints were made with great care and by skilled workmen. In practice it is not possible to count on the conscientious workmanship which is essential if

such reliable joints are to be obtained. Consequently it is advisable to relieve these points of as much stress as possible and to design the line with this end in view.

The " dead ending " of a line at a strain tower or pole or at a corner pole can be carried out with any of these shackles, terminal clamps, or riveted connections. The first two methods are now seldom used, as they are expensive and not too safe. Riveted clamps are quite satisfactory for the purpose provided the tension on the line is not very great. The conical grip clamp is also suitable. The cable end is attached in the way described above for conical grip clamps and the loop on the other side of the clamp is slipped over the insulator. The loop is of galvanised drawn steel wire rope, which is sufficiently flexible to bed well against the insulator. A separate screw is often fixed at the top of the junction piece for the purpose of making electrical contact with the outgoing wire, and is a specially handy addition.

The line can also be attached to a strain insulator by means of a special metal cap cemented to its top and fitted with a terminal as shown in Fig. 155.

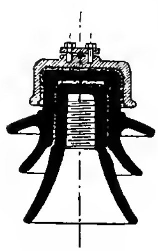


Fig. 155.

The rules of the V. D. E. only permit joints in overhead lines to be made by soldering, screwing or equivalent methods. Merely twisting together or the use of a twisted sheath joint is not permissible because of the high resistance introduced by any existing oxide coating or by an oxide coating forming in the course of time. On the other hand, soldering is only applicable to hard drawn copper wire if the joint is relieved of mechanical stress.

For soldering copper a soft solder composed of 55 parts of tin and 45 parts of lead and melting at about 200° C. is used. A solder flowing more readily than this is obtained by using equal quantities of tin and lead and pouring off the half-solidified crust.

A great many soldering compounds have been placed on the market for the purpose of simplifying the process by providing an easily running solder with the flux, or deoxidising agent, ready mixed with it. They are especially suitable for overhead line work, as they tend to improve the quality of the soldering done.

The flux must be free from acid, as acids attack the soldered joint and its surroundings unless carefully removed after the joint has been completed.

Most commonly resin and soldering tallow are used. The latter consists of 1 lb. of tallow, 1 lb. vegetable oil, $\frac{1}{2}$ lb. powdered resin, and $\frac{1}{5}$ pint of salammoniac solution. This mixture is entirely free from acid and a very good flux.

The soldering of aluminium presents great difficulties in practice, partly because of the rapid reoxidisation of the cleaned parts and partly because of the easy disintegration of the alloys used as solder.

There is no need, therefore, to describe the different methods that have been suggested. Joints on the line and branch connections are best made by some such mechanical device as the Arld twisted sheath joint or by means of screw clamps. The strong electro-positive action of aluminium is liable to set up electrolytic action when it is in contact with other metals if moisture is present. Spliced

or twisted joints must therefore be covered with a protective coating and weatherproof cover to keep out moisture.

In spite of every precaution, however, the electrical resistance of such a joint is sure to be higher than that of the unjointed wire, and it will gradually increase with time.

A good joint can be effected by means of previously prepared terminals made of two metals, *e.g.*, copper and aluminium, soldered together. In this way incomplete contact between the aluminium line wire and any different metal can be avoided.

14. ARRANGEMENT OF THE WIRES.

Distance from the Ground.

The Board of Trade regulations specify that the minimum height of a line from the ground shall be 20 feet, and 25 feet when crossing a public road, canal or railway (the German rules give 19·5 and 22·8 feet respectively). These figures apply to the line itself, and not to guard wires or nets. In most cases the actual height of the line above roads is determined by the requirements of the postal authorities with regard to telegraph lines running under or close to the transmission line (the German rules specify a minimum distance of 6·5 feet under the most severe conditions—even including a breakage of all the line wires in one of the neighbouring spans).

Distance between the Wires.

The distance apart of direct current lines of opposite polarity depends on the physical conditions, length of span, sag, and arrangement of the wires. Lines arranged in a staggered manner can be run closer together than lines run horizontally side by side. The deviation produced by wind pressure is, for a given cross-section, dependent on the specific gravity of the line material and on the sag. With a given length of span, therefore, heavy lines under considerable mechanical tension require less separation than lines of lower specific gravity or with less mechanical stress. Although, in general, the various lines will swing in synchronism, yet occasionally, owing to whirlwinds or to the settling of large numbers of birds on the lines, this cannot be relied on, and contact occurs unless ample separation is allowed. Whilst with direct current lines the maximum separation is only limited by mechanical considerations and the question of cost, alternate current lines have to be run as closely together as possible in order to reduce their self induction or inductance. The limit in these cases is decided by safety of operation and, in the case of the higher voltages, by the question of brush discharges. For very long lines the question of electrostatic capacity also comes in.

In schemes up to about 50,000 volts the separation of the lines is generally determined by the safety of operation (avoidance of contact between wires, the certain extinction of any accidental arc, etc.). The horizontal distance apart in the case of 150 to 200 foot spans should be at least 12 inches and the vertical distance at least 8 inches. The approximate horizontal distance apart A in inches can be determined in terms of the span a in feet and the voltage E in kilovolts by the following empirical formula :—

$$A = \cdot 048\, a + 4\sqrt{E} \quad . \quad . \quad . \quad . \quad . \quad 67^*$$

* This applies to copper conductors. For aluminium the distance must be increased about 25 per cent.

Another rule due to Häfner, and applicable to spans of 150—165 feet, is

$$A = 7 \times \sqrt{E} \quad . \quad . \quad . \quad . \quad . \quad . \quad 68$$

Whilst Uppenborn gives the formula

$$A = 16 \sqrt[4]{E} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 69$$

This last gives results which are too small for the higher voltages. Formulæ 68 and 69 take no direct notice of the length of span.

The results obtained by formula 67 for copper wire with various voltages and spans are collected in Table 33. For aluminium these values have to be multiplied by 1·25.

TABLE 33.

Working Voltage.	Length of Span in Feet.																
	165	230	295	326	360	390	425	460	490	525	555	590	620	655	980	1,300	1,630
							Approximate separation in inches.										
110	12	14	16	18	20	20	22	24	26	28	28	30	32	34	49	65	81
220	12	14	16	18	20	20	22	24	26	28	28	30	32	34	49	65	81
380	12	14	16	18	20	22	24	24	26	28	30	32	32	34	49	65	81
500	12	14	18	20	22	22	24	26	28	28	30	32	34	36	51	67	83
1,000	—	16	20	20	22	24	26	26	28	30	32	34	34	36	51	67	83
3,000	—	18	22	24	24	26	28	30	32	32	34	36	38	40	55	71	87
5,000	—	20	24	26	28	28	30	32	34	34	36	38	40	42	55	71	87
10,000	—	24	28	30	30	32	34	36	36	38	40	42	44	44	59	75	91
15,000	—	26	30	32	34	34	36	38	40	42	42	44	46	48	63	79	95
20,000	—	—	32	34	36	38	40	42	42	44	44	46	48	50	65	81	97
30,000	—	—	—	38	40	41	44	46	46	48	48	50	52	54	69	85	100
40,000	—	—	—	—	—	44	46	48	50	52	52	54	56	58	73	89	104
50,000	—	—	—	—	—	—	—	—	52	54	56	58	60	60	75	91	106

The necessary separation was determined by practical experiment in the case of the Rjukanfos transmission scheme.* A section of line in the most unfavourable spot was erected for this purpose with a span of 700 feet. Three copper cables each of ·23 square inch section were suspended at distances of 23½ and 31½ inches respectively in a normal manner, and were provided with indicating devices to show when the lines came into contact. The experiment lasted from the beginning of February to the beginning of May, and showed that with the 23½-inch distance the lines swung into contact whenever a strong wind occurred, whilst the 31½-inch distance only permitted contact on one occasion, when a hurricane was blowing. When the separation was later increased to 39½ inches no contact occurred. The well-known fact that the various lines generally swing synchronously was also observed to hold in the case of these experiments. The deflection of the lines was often, during a strong wind, several times as great as the distance apart of the wires without in any way reducing this separation as far

* See Elektrische Kraftbetriete und Bahnen, 1912.

as could be seen. The contacts, when they occurred, were never initiated by the large swinging motions of the cables, but by sharp local blasts or whirlwinds which started vibrations of short wave length.

Grouping of the Wires.

When several parallel connected lines are mounted on the same poles the arrangement in the case of direct current circuits is simply determined by con-

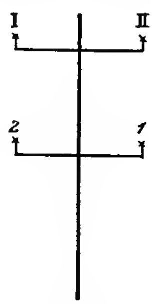


Fig. 156.

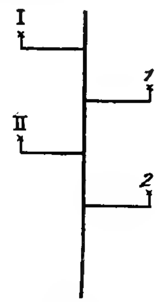


Fig. 157.

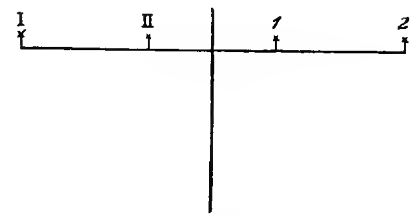


Fig. 158.

siderations of convenience and care in supervision (minimum number of crossings at distributing and feeding points, convenient arrangement of branch circuits, and house services) and by the question of the best distribution of the mechanical stresses on the poles (heavy wires at the bottom, earthed wire at the top, etc.).

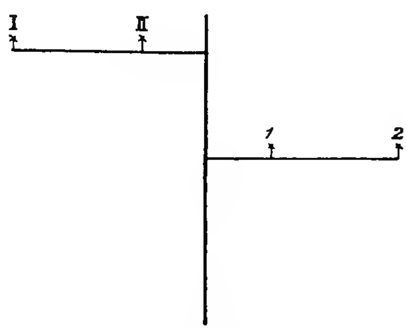


Fig. 159.

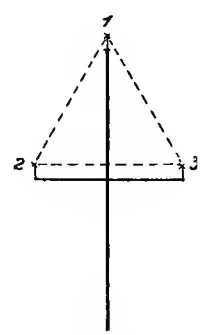


Fig. 160.

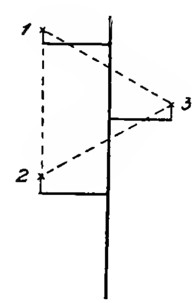


Fig. 161.

In the case of alternate current lines the grouping has to be considered also from a further point of view, viz., that of keeping the resulting self-induction down to the lowest possible value.

A given number of wires can be arranged on the poles in a variety of ways, but there is always one way which gives a minimum of self-induction. The best arrangement from this point of view is not always applicable in practice, because the simplicity of the branch connection and the general accessibility of the lines are usually of more importance than a slight increase in inductive resistance.

A few of the usual groupings will be discussed here :—

(1) *Two Single-phase Circuits connected in Parallel.*—Here the best arrangement is that shown in Fig. 156. Then follow in order Figs. 157, 158, 159.

(2) *A Single Three-phase Circuit.*—The wires should be placed at the angles of an equilateral triangle (Figs. 160 and 161).

(3) *Two Three-phase Circuits in Parallel.*—If the six wires are placed at the angles of an equilateral hexagon in such a way that the parallel pairs are diametrically opposite (Fig. 162), the mutual induction of the two circuits will diminish the self-induction of the various individual circuits and thereby the effective self-induction of the whole. Almost the same result is attained by the arrangement shown in Fig. 163, where the three wires forming one circuit are situated at the angles of similar triangles. The nearer these triangles are to equilateral ones the better the result.

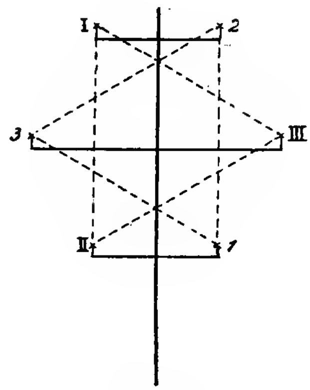


Fig. 162.

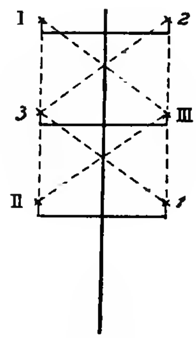


Fig. 163.

The groupings most commonly adopted for transmission lines are those shown in Figs. 164 and 165. Electrically the two are identical, as the equilateral triangles are simply reversed. Owing to the different distances between wires of

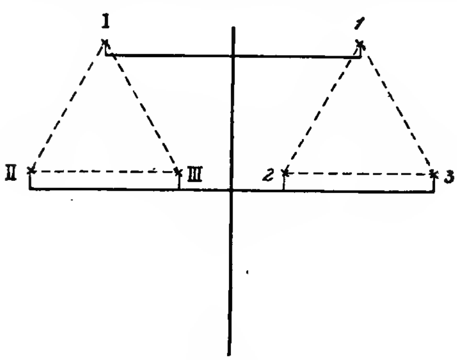


Fig. 164.

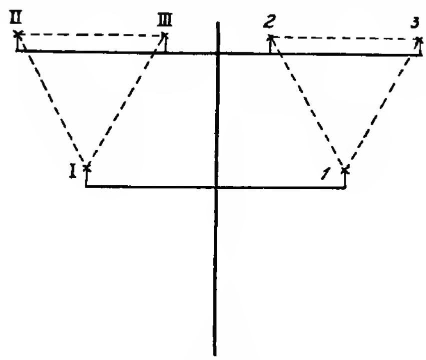


Fig. 165.

one circuit and wires of the other the voltages induced by lines I., II., and III. in the three phases of the other circuit are unequal. With moderate currents and moderate lengths of line the mutual inductive action can be neglected in comparison with the self-induction effect if one of the circuits is given one complete transposition.

The same holds for the arrangements in Figs. 166 and 167. Fig. 166 is preferable, but in both groupings the inequalities between the separate phases

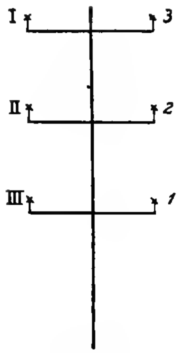


Fig. 166.

of each circuit are considerable. Although the arrangement of Figs. 162 and 163 give minimum inductance they are not to be recommended, because, even when one circuit is disconnected from the supply, live lines exist on both sides of the pole and so prevent repair work being carried out safely on the dead circuit. The arrangement chosen should be such as to keep the two circuits entirely distinct, and in many cases they are separated by earthed safety screens of wide-mesh wirework.

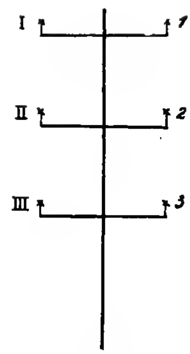


Fig. 167.

Transposition of the Wires.

The voltage drop in a three-phase circuit is a minimum and equal in all three phases when the wires are situated at the angles of an equilateral triangle (Figs. 160 and 161). If the wires are placed in one plane (Fig. 168) the inductive drop in the outer wires is greater than in the centre one. In order to avoid unequal phase voltages at the far end of the line from this cause it is usual to transpose the wires once at suitable points between the beginning and end of the line (Fig. 169). When operating telephone wires are run on the same poles under a H.T. line, disturbances are produced in the former by electrostatic and electromagnetic induction from the latter, which, owing to the great sensitiveness of the telephone, may render speech difficult or even impossible.

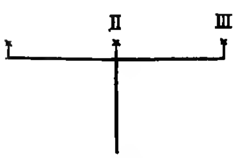


Fig. 168.

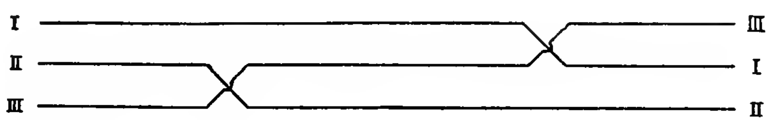


Fig. 169.

In order to reduce this effect the two telephone wires should be kept as close together as possible and as far away from the H.T. line as possible (not less than 4 feet), and at the same time they should be transposed (or crossed) frequently. The transposition points should be so selected that one occurs at every branching point of the H.T. circuit; and the distance between transposition points should be 400 to 600 yards.

In order still further to improve the speech conditions the H.T. line itself can also be transposed at intervals. This becomes essential when postal lines run parallel and close to the power line. The separate line sections conveying equal load are divided into three, or in very long sections into six, equal lengths, and the lines are so transposed that each phase occupies a certain position (for instance the bottom position) for the whole of one of these lengths (see Fig. 170).

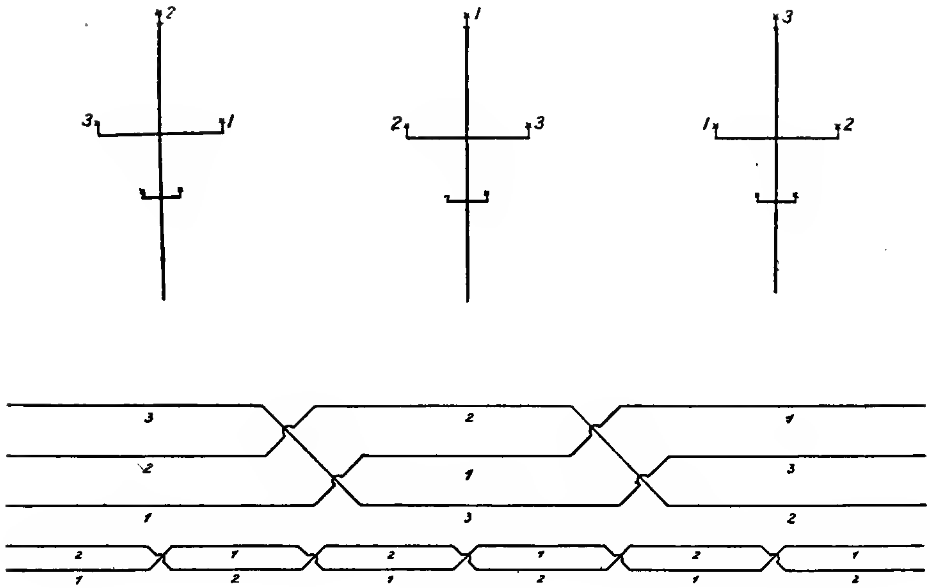


Fig. 170.

The transposition may advantageously be carried out at masts with double insulators. In the case of wooden pole lines two separate poles about 3 to 5 yards apart are often provided at the transposition points.

If transposition is carried out on long spans accidental contacts are likely to occur owing to the reduced distances between wires at the crossing points.

15. EARTHING.

THE earthing of a body means its connection to the earth in such a way that it cannot attain a potential dangerous to anyone touching it when standing uninsulated on the ground.

A distinction must be made between earthing for the purposes of operating the scheme and earthing for protective purposes. The chief cases of earthing for operative purposes are those of the earthing of the middle wire of three-wire systems and the earthing of the neutral points of multi-phase circuits. By this earthing the maximum voltage to earth is halved in three-wire systems and is reduced in the ratio of $\sqrt{3} : 1$ in three-phase systems, so that systems having voltages of $2 \times 250 = 500$ or $\sqrt{3} \times 250 = 435$ can still be classed as low-voltage ones.

The laying of the earthed wire must be carried out just as carefully as that of the other wires, since a break in it may permit dangerous voltage rises on the outers to occur. An earthed wire must not be replaced at intervals by the earth itself or by portions of buildings, though metallic building structures may advantageously be used to augment the effective section of the specially laid earthed wire.

Protective earthing has to be carried out when risk exists of parts of structures not intended for current-carrying purposes becoming charged to dangerous voltages either through accidental contact with H.T. circuits or through current creeping across from the H.T. circuit. It operates by providing a good conducting path to earth for any such leakage currents. Consequently, when a human body comes into contact with the structure, only an infinitesimal current will flow to earth through it whilst the greater part passes through the metallic connection to earth. The relative values of these two currents is dependent on the existing condition of the earth connection, and its resistance should therefore be kept permanently at the lowest possible figure. The important *rôle* of this protective earthing, viz., the prevention of danger to persons, makes careful workmanship and avoidance of all risk of mechanical or chemical damage imperative.

The cross-section of the earthing wire and the surface of the earthing plate must be chosen to suit the expected volume of current flowing to earth. In overhead line systems it is advisable to make the cross-section of copper earthing wires at least ·04 square inch and of iron earthing wires at least ·16 square inch. The copper should be tinned and the iron galvanised. Earth wires should be as open to inspection as possible and, where laid in the earth, should be of solid wire not of stranded cable. Good metallic contact at the connection points is essential. When connecting the earth wire to iron intermediate lead washers

should be inserted; and the connection should be covered with a waterproof covering or paint.

At places where damage is especially likely to occur the wire should be carried in thin earthenware pipes, and these should be filled in with asphalt. The earth wire on iron masts should, preferably, be laid on the inside of the mast and be clamped tightly to it.

Should it be necessary to protect an earth wire against mechanical damage because of its being laid on the outside of a mast or building or against chemical damage through the action of the soil, this can be done by running the wire in iron tubing and filling this up solid with compound.

All earth wires should be run as straight as possible and without any sharp corners.

Iron structures, *e.g.*, lines of piping (gas or water pipes), can be used as auxiliary electrodes by being connected to the earth wire. These connections must be carefully soldered whatever other means of making contact may be employed in addition.

Earth plates should only be employed when a permanently damp stratum exists at not too great a depth. The galvanised or lead-covered iron plates, having at least 1 square yard of surface and a thickness of at least $\frac{1}{8}$ inch, should be embedded in the soil straight (not rolled up). The connection to the earth wire can be carried out as shown in Fig. 171. The wire is bent through slots cut in the plate in a loop around the plate and back on itself again. The portion of the wire lying between the slots is then soldered to the plate. The wire must be so placed in the earth that the ramming home of the earth cannot damage the connection.

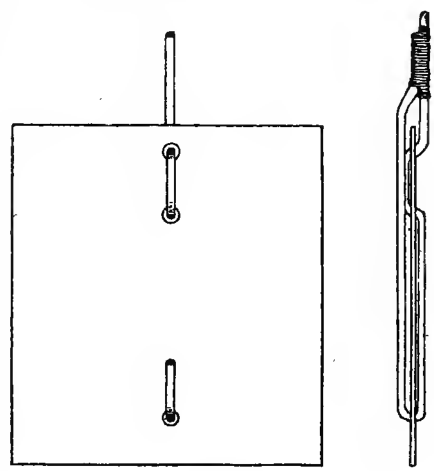


Fig. 171.

A better earth contact is obtained if, in place of one large plate, several smaller ones are used buried at distances of a few yards from one another.

Wire netting, with wire of not too small section, also is preferable to the single solid plate.

Suspension of the earth plate in flowing or stagnant water does not give satisfactory results because of the high specific resistance of water.

In stony, dry soil the contact resistance of the plate can be diminished by surrounding it with fine ground coke (3 or 4 cwt.).

When the surface water can only be reached at depths of 2 or 3 yards it is advisable to use tubular electrodes consisting of 2 or $2\frac{1}{2}$ inch diameter gas piping $2\frac{1}{2}$ to 3 yards long and provided with a ramming point at the end. At the upper end collars for connecting the earth wire should be provided. The junction should also be soldered and then painted over with hot tar. In order to improve the

contact the pipe and the upper part of the soil around it can be sprinkled with salt. In this case the pipe should have holes drilled in it all along its length. The pipes are driven vertically into the ground as shown in Fig. 172. In dry soil several such pipes should be used.

The best mode of earthing individual masts is by the employment of band iron electrodes radiating away from the mast (Fig. 173) at a depth of 20 to 30 inches and each having a length of 6 to 10 yards. By combining the strips into a sort of rough network and connecting this to the mast and foundation a large contact surface is obtained and the surrounding earth is brought to the same potential at all points, thus lessening the possible danger when making contact with the mast.

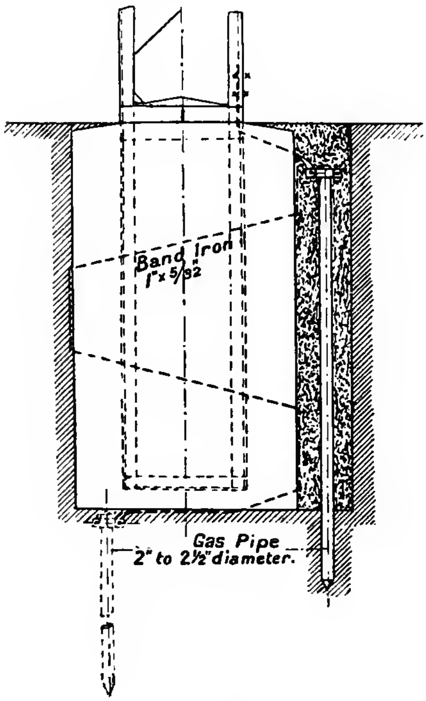


Fig. 172.

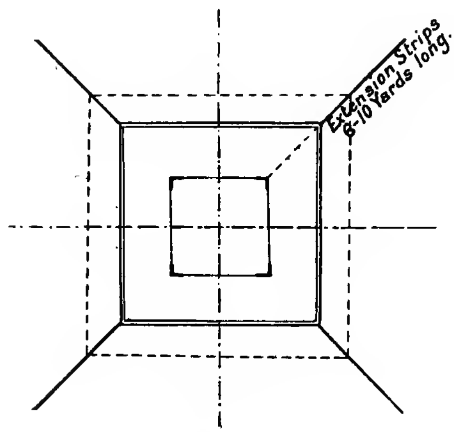


Fig. 173.

Bad earth connections have repeatedly been the cause of accidents. If the earth electrodes do not lie in the surface water the current is liable to evaporate the moisture near the earth plate, and an arc even may be started between the plate and earth, which vitrifies the sand and clay, and this may insulate the plate and necessitate the earth currents finding another way back. Under these circumstances a high potential gradient will be set up in the neighbourhood of the mast, and contact with the mast, and even approach to it, becomes dangerous.

In such cases the best solution is found in laying a through-running earth cable, this cable being earthed by one of the above-described methods at intervals of 500 to 700 yards. In this way a number of return paths are made available for the earth current.

16. CROSSINGS OVER POSTAL WIRES, RAILWAYS AND ROADS.

POWER lines carried over or approaching postal lines, railways, or roads must either be so designed that in case of the breakage of a power line no danger results, or else they must be so conservatively dimensioned in all their details that the falling of a line or the overturning of a mast or tower is practically impossible.

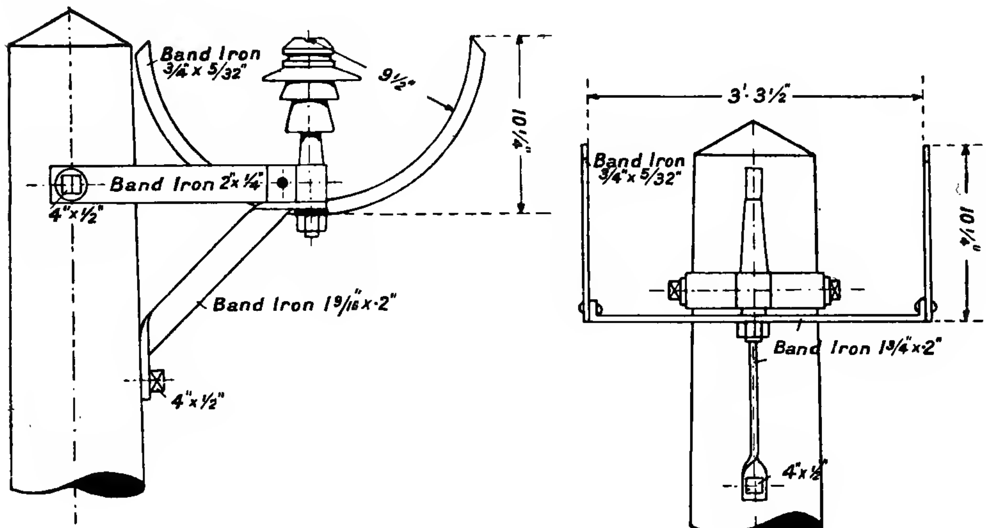
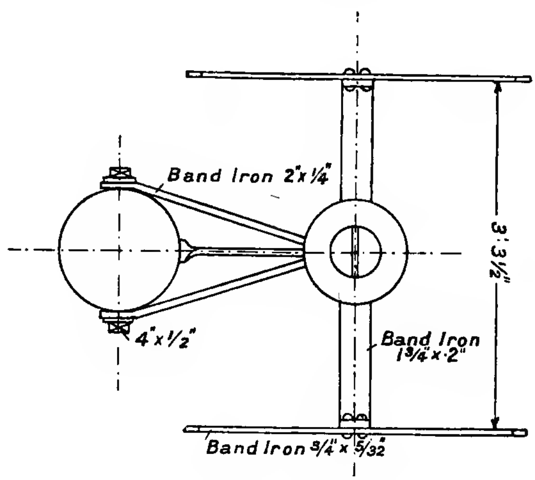


Fig. 174.



A great many methods of satisfying these requirements have been introduced.

(1) *Earthing Bows* (Figs. 174 and 175).—These are so arranged that a falling wire is bound to come into contact with them and thereby becomes earthed. Their reliability depends chiefly on the good condition of the earthing of the bow. The distance of the wire from the bow should be kept as small as possible to make

quite certain of contact occurring before the wire end can reach the ground or objects on the ground. A certain minimum distance, however, is essential in

Fig. 175.

order to cope with the perching of birds on the structure and with the unavoidable swinging of the wire. For voltages over 500 the distance should not be less than 8 inches.

The earthing bows are made of iron, and the contact face should be thickly galvanised unless the copper earthing wire is carried across the contact face.

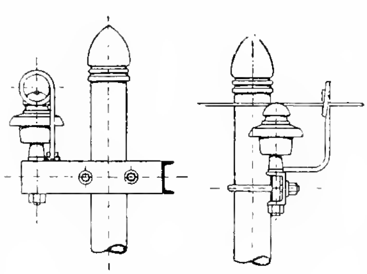


Fig. 176.

Earthing eyes or short-circuit rings (Fig. 176) can only be used for low-tension circuits, because the risk of contact by birds is even greater than with earthing bows. The eyes are made of hard drawn copper wire ·2 to ·25 inch in diameter, as this is the safest material for ensuring contact with the falling wire.

(2) *Safety Couplings* are arranged to switch off the wire from the supply as soon as a break occurs. Two designs are in use—the Gould coupling (Fig. 177) and the Hesse coupling. The hooked conducting pieces are fixed to the insulator and grip the terminal pieces fixed to the end of the line, and the line tension keeps the two in contact. When the tension ceases owing to a wire breaking, the ends of the wire are free

to drop out. The use of these couplings involves the staggering of the various lines in a vertical direction, and adds appreciably to the line resistance. Further, when a wire snaps suddenly it may be jerked upwards, and in falling may come into contact with other uninjured H.T. wires, and the hanging ends then become a danger.

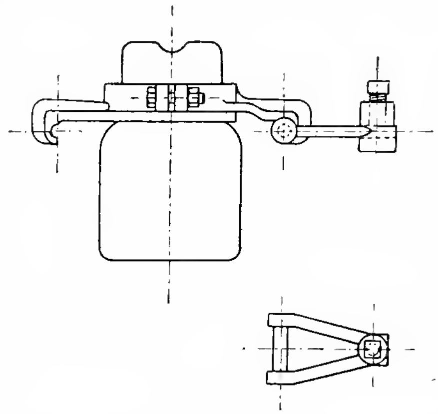


Fig 177.

(3) *Protective Nets*, though sometimes used, are a constant source of trouble to those in charge of the line. In the first place, their appearance is not pleasing; then, if designed on ample lines they add enormously to the stresses on the masts, whilst if the design is cut fine they are liable to be damaged by snow and ice loads, or through the flue gases of locomotives, or through rust. Large mesh netting is not permissible, as the broken wires may slip through: small mesh netting, on the other hand, encourages the collection of snow and is subjected to heavy

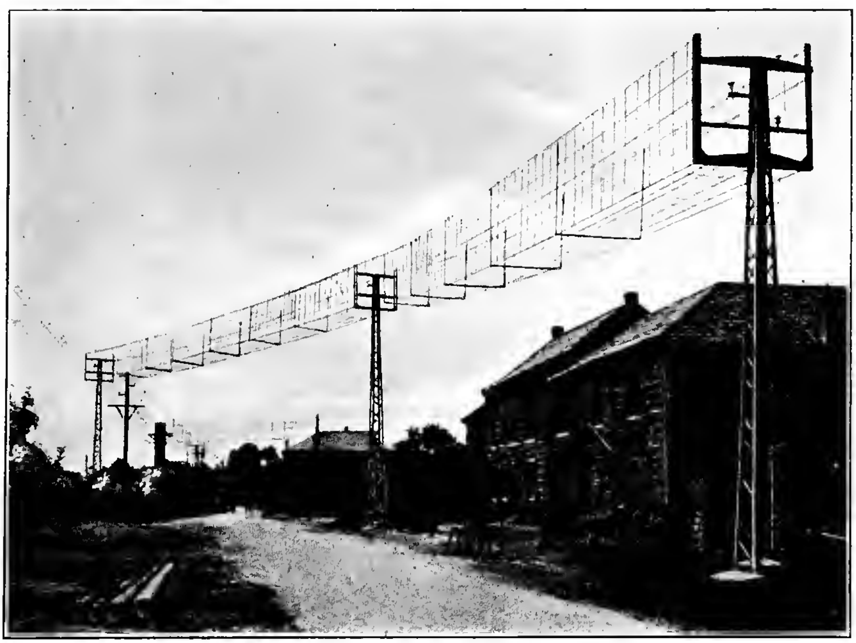


Fig. 178.

wind stresses. Both have the common disadvantages that, if the distance between wire and net is not ample, they are liable to swing into contact in a strong wind: swaying boughs or objects thrown at the line from the ground are liable to get

caught, and, finally, a falling line may cause the thin wires of the netting to be melted by the heavy current to earth.

The general safety of operation of the line is, in fact, diminished when safety nets are employed, and they are no infallible protection even against falling wires They should, therefore, only be employed in cases where no other form of protection is possible. This is the case, for instance, when postal wires are run above a H.T. power line.

The protective nets are sometimes closed on all sides, sometimes open at the top (Fig. 178), and sometimes trough-shaped (Fig. 179). The type closed on all four sides is essential when postal wires are carried over the power line and when at the same time the power line has to be prevented from falling. The commonest

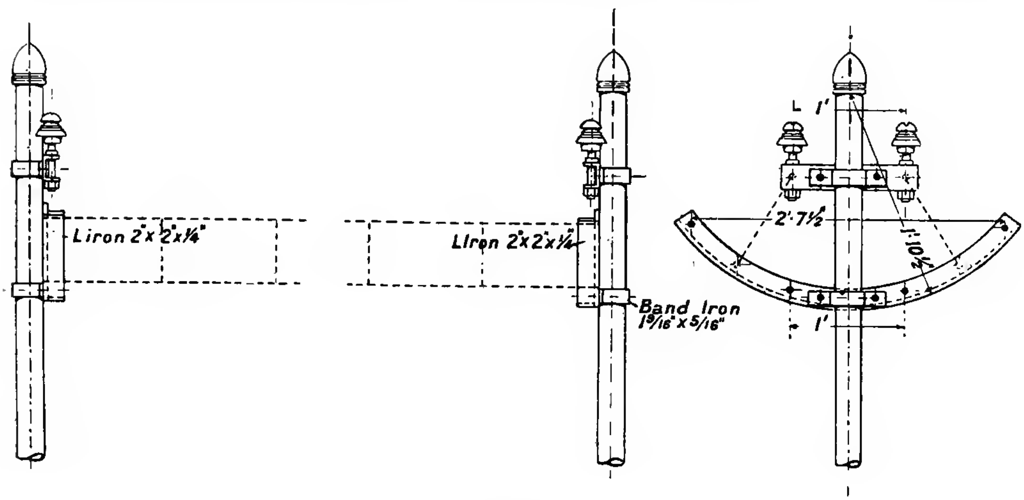


Fig. 179.

arrangement is, naturally, the one with the open top ; the sides being raised 8 to 12 inches above the highest line wire.

The trough-shaped type only becomes effective as a safeguard against falling wires if the sideway projection is at least equal to half the height of the highest wire above the net. The arrangement shown in Fig. 180 is quite ineffective. This is a case of a 50,000-volt three-phase line, and the span at the road crossing is about 130 feet. A falling wire here would only be caught by the net under unusually favourable circumstances. Such a high voltage as this also increases the danger of burning out the wire of the netting through the heavy earth current.

Trough-shaped nets placed over the power line must have a narrower or more open mesh, according to the direction taken by the postal wires requiring protection.

Box-shaped nets should, with a maximum length of span of 130 feet, have at least 16 inches separation between the line wires and the longitudinal wires of the net. The distance between the lowest line wire and the cross wires of the net should be such that even with the maximum sag a clearance of at least 12

inches exists. The longitudinal wires should be of ·16 to ·2 inch diameter galvanised steel and the cross wires of ·08 to ·1 inch diameter galvanised iron. These cross wires should link the longitudinal wires together at intervals of 30 to 40 inches. For the purpose of adjusting the tension the longitudinal wires should be finished off with stretching screws at one end connected to the angle iron end frame (Fig. 181). Protective nets must be well earthed.

Fig. 180.

(4) *Special Safety Suspensions.*—According to the regulations of the V. D. E., protective nets or other safety devices may be omitted if the transmission line installation is carried out in a specially secure manner. This additional security is assumed to be present if the line tension is reduced to only half the values usually permissible, if the masts are specially amply dimensioned, and if the insulators and their supports are so arranged that in case an insulator or a wire breaks the latter cannot fall or, at any rate, is earthed before it falls. These requirements are completely fulfilled by the use of the special safety suspension (Fig. 182) due to the Allgemeine Elektrizitäts Gesellschaft. In this the line wire is held by three distinct insulators, so that if one breaks the line will still be supported without any appreciable change by the other two. It will be seen that the two auxiliary supports are continued backwards. This is done because, without it, when a voltage rise occurs, through internal switching operations or through atmospheric effects, the endmost insulators, being at the end of open-circuited lines, become points of maximum voltage rise and are liable to breakdown. This

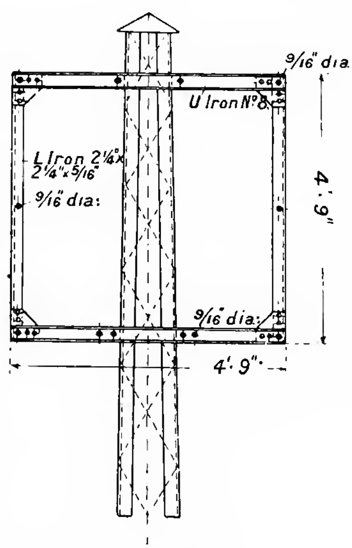


Fig. 181.

actually occurred on a number of the earlier examples, but the continuation of the auxiliary wires has greatly diminished the trouble and the resulting interruptions of supply.

Professor Dr. Ulbricht * has devised the arrangement shown in Fig. 183 for the State Railways of Saxony. Each line conductor consists of two cables supported on separate insulators and connected together by a zig-zag arrangement of cross wires. In this way each conductor is in the form of a narrow network suspended in a horizontal plane and appearing little thicker than the ordinary line wire. If one of the longitudinal cables breaks the net sets itself on the slant, and the fact that something is wrong at once becomes noticeable from a distance.

The connection of the cross wires to the longitudinal wires is carried out with Hofmann's riveted joints. The construction is not simple and is not easily carried out on the spot. The cross wires have to be carefully dealt with if the riveting of the joints is not to damage the longitudinal wires. Also, unless great care is taken in erection, large additional stresses may be set up in the longitudinal

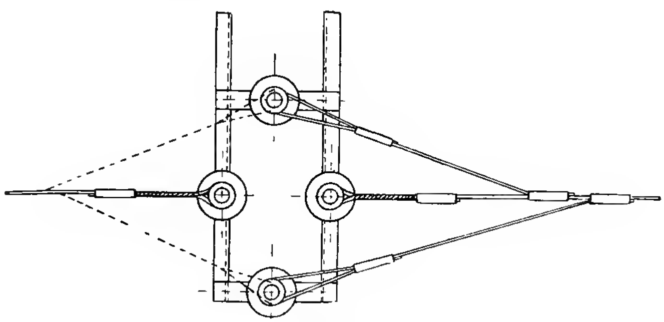


Fig. 182.

wires, thus greatly reducing the factor of safety. The supporting structures also become considerably heavier and more expensive owing to the increased weight of line and the additional load of ice or snow to be provided for.

The safety suspension of the A. E. G. is considerably simpler and, consequently, at least as reliable in practice as this network conductor. A photograph of some network conductors in position is shown in Fig. 184.

(5) *Bridge Construction for Crossings* (Figs. 106 and 185).—These were at one time commonly specified by the authorities. Although they, of course, prevent the falling of wires, they are very expensive, so much so that some schemes have had to be abandoned owing to this additional expense. At the present time these bridges are only used in exceptional cases.

Finally, one of the simplest possible safety arrangements in principle is to prevent the wire ends, when a break occurs, from approaching dangerously near to the ground (the rules of the V. D. E. specify a minimum distance of 3 metres). Of course this method is seldom applicable, as it involves either very short spans or very tall masts.

* Elektrische Kraftbetriebe und Bahnen, 1910, p. 303.

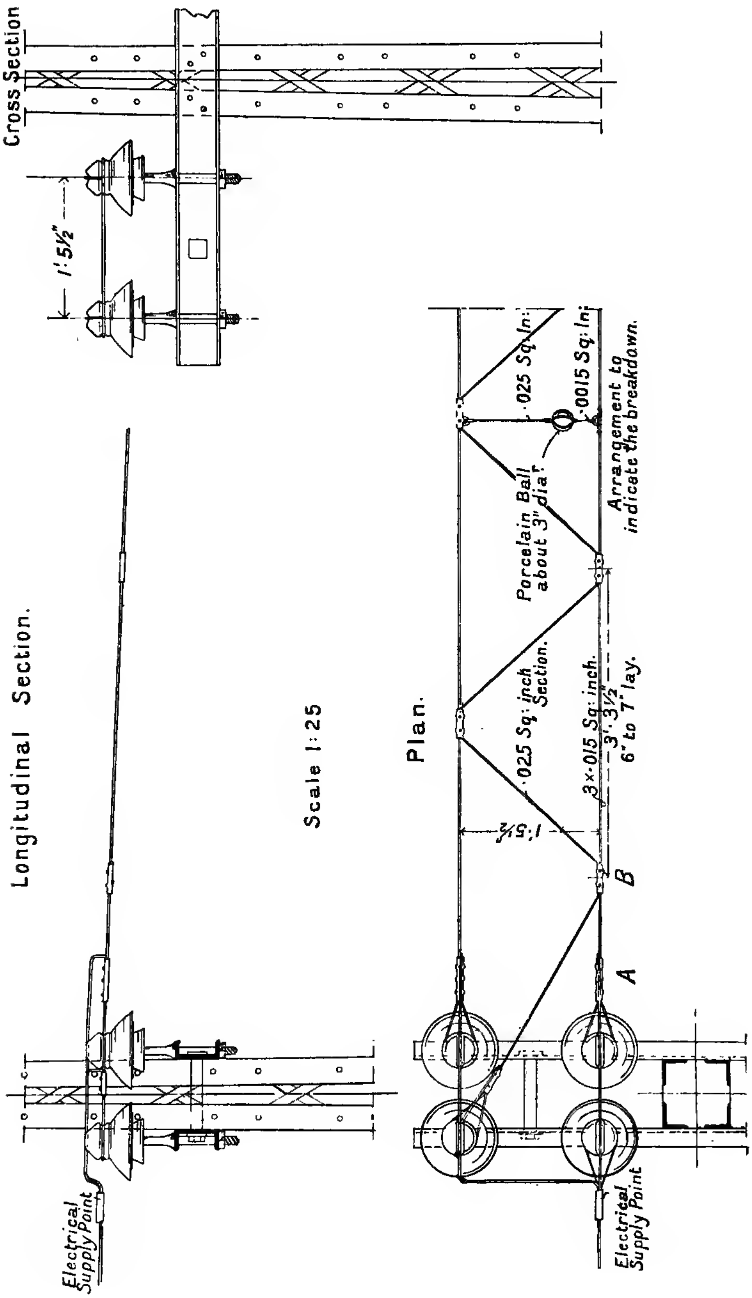

Cross Section
1' 5½"
Longitudinal Section.
Electrical Supply Point
Scale 1: 25
Plan.
·025 Sq: In:
·0015 Sq: In:
Arrangement to indicate the breakdown.
Porcelain Ball about 3" dia.
·025 Sq: inch Section.
3×·015 Sq: inch.
3'·3½"
6" to 7" lay.
1' 5½"
B
A
Electrical Supply Point

Fig. 183.

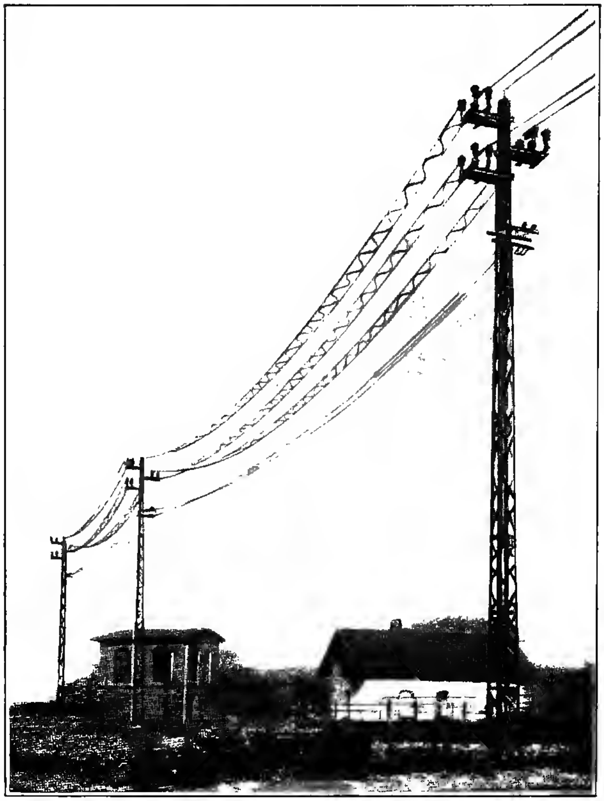


Fig. 184.

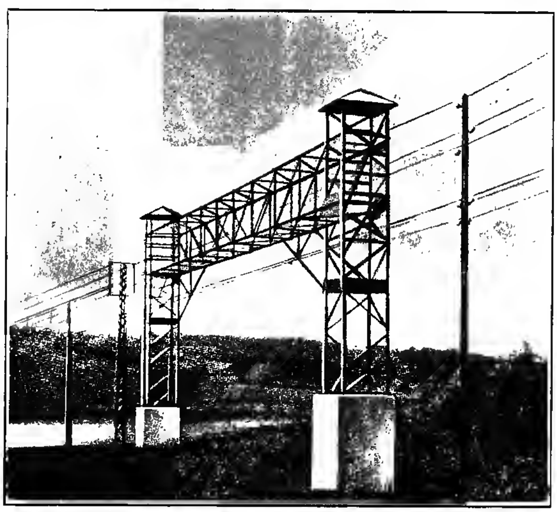


Fig. 185.

Elaborate rules have been drawn up by the German postal authorities with regard to the safe crossing of postal wires by overhead power lines. Accompanying these rules is a detailed sample calculation for an imaginary case showing exactly how the various stresses and factors of safety are to be arrived at. This calculation is reproduced below as a useful guide in similar cases. The following data are employed :—

Fig. 187 shows the relation between sag and length of span for hard drawn copper wire based on the fact that the maximum stress in the line shall not exceed 5,700 lbs. per square inch either at — 5° C. with additional ice load or at — 20° C. without additional load (giving a factor of safety of 10 in normal copper wire with a breaking stress of 57,000 lbs. per square inch).

The weight of 1 foot of copper wire, 1 square inch in section, is taken as 3·9 lbs. or $\delta = 3{\cdot}9 \times q$ = weight in lbs. per foot run (q being the sectional area of the conductor in square inches).
Young's modulus of elasticity $= E = 18{\cdot}5 \times 10^{5}$ lbs. per square inch.
Thermal expansion co-efficient $= \alpha = 1{\cdot}7 \times 10^{-5}$.
$\delta_2 = 6{\cdot}6 \times q$ = ice load in lbs. per foot run.
$\delta_e = \delta + \delta_2 = 10{\cdot}5 \times q$ ($= 2{\cdot}67$ times δ) = total load per foot run due to weight of wire and ice.

The arrangement of the crossing is shown in Fig. 186, and the type of suspension in Fig. 192.

Static Calculation.

For the safety suspension of the overhead lines of the ...... Power Company at the points where they cross Post Office lines.

I. *General.*

(1) Working voltage : 10,000 volt.
(2) Nature of supply : 3-phase.
(3) Position of the [5] crossings (Fig. 186).*
(4) Description of the safety suspension. At all [5] crossings the triple insulator type of safety suspension will be employed. The line is strained to the middle one of three pin insulators mounted side by side on the same cross-arm, and at the same time it is connected by auxiliary wire ropes not more than 1 yard long to the two outer insulators. The auxiliary wire ropes are to be attached by means of screw clips (type......) (see Fig. 192).

Earthing.—Every mast and the guard wire will be earthed by means of a galvanised iron plate 11 square feet in area lying below the level of the surface water.

* The calculation is only carried out here for one of the crossings.

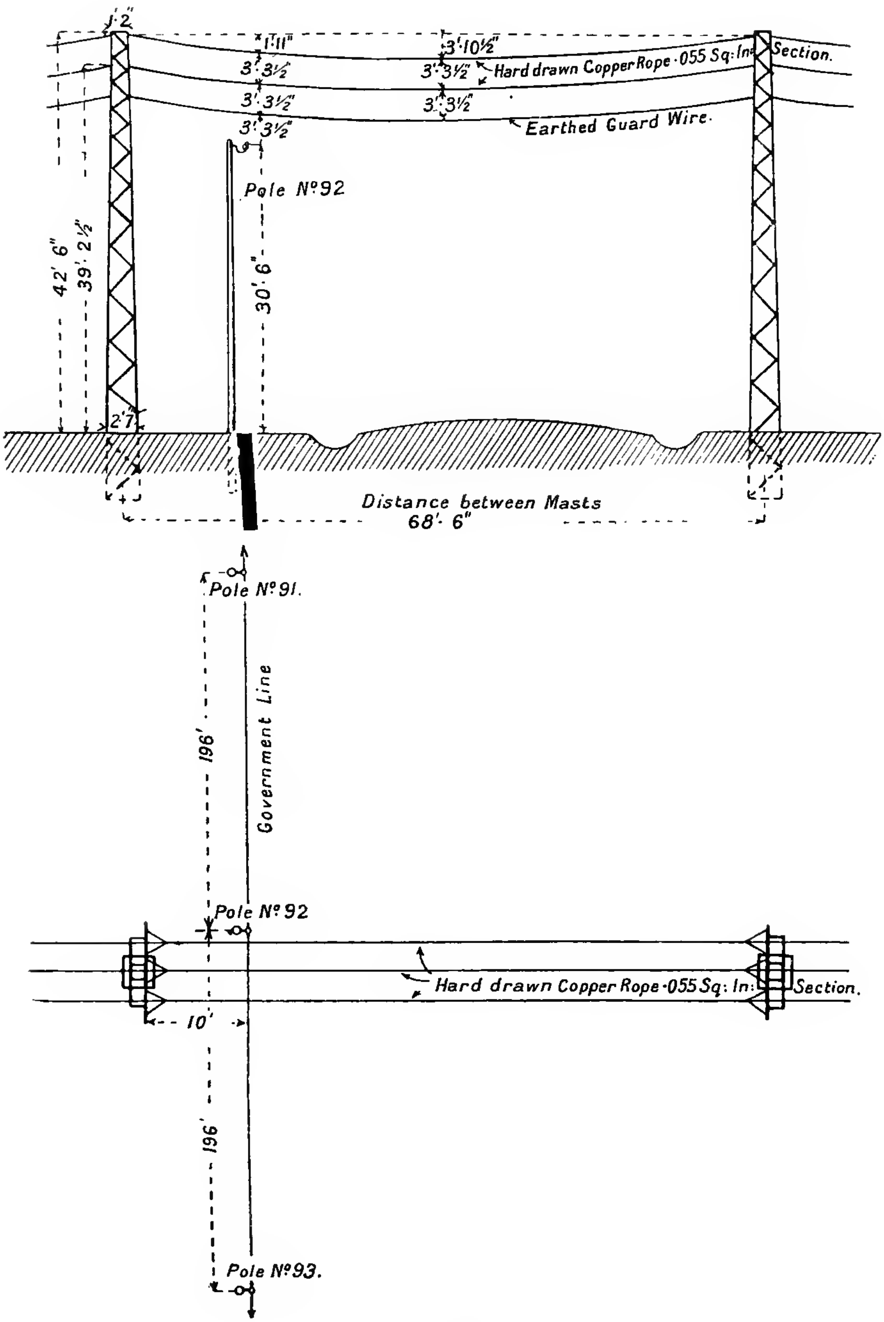

2"
1'11"
3'10½"
3'3½"
3'3½"
3'3½"
3'3½"
3'3½"
3'3½"
Hard drawn Copper Rope ·055 Sq: In: Section.
Earthed Guard Wire.
Pole No. 92
42' 6"
39' 2½"
30' 6"
2'7"
Distance between Masts
68'-6"
Pole No. 91.
196'
Government Line
Pole No. 92
Hard drawn Copper Rope ·055 Sq: In: Section.
10'
196'
Pole No. 93.

Fig. 186

Materials used for the Safety Suspension.

Part of the Structure.	Material used and its Dimensions.	Breaking Stress in lbs. per sq. inch.	Remarks.
H.T. transmission line	Hard drawn copper ·054 sq. inch section.	57,000	
Auxiliary wire ropes.	Hard drawn copper ·054 sq. inch section.	57,000	
Lightning conductor.	Steel wire rope ·054 sq. inch section.	57,000	
Guard wire . .	Galvanised iron wire ·2 inch in diameter.	57,000	
Masts with cross-arms and insulator pins.	Wrought iron . .	57,000	Three different types of mast (see sketches Nos..... attached).
Insulators . .	Porcelain . . .	—	Tested up to 40,000 volts.

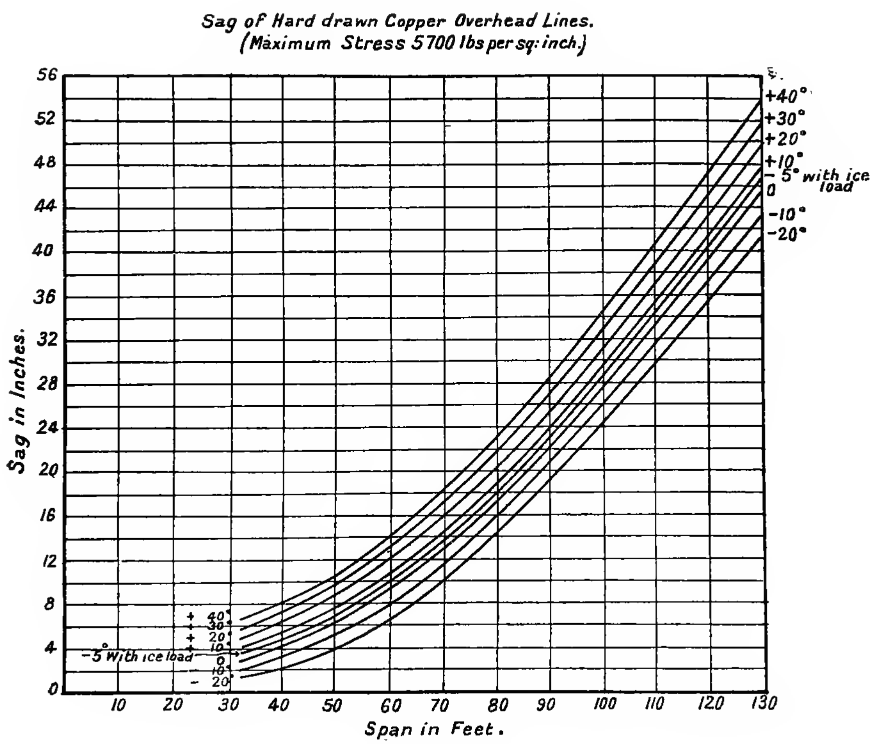


Fig. 187.

II. Calculations for Crossing No. 1.

A. *Line Sag.*

1. In the crossing span (Fig. 186).

		Inches.
Span of the power line (s)		822
Sag of the power line (read off the curve of Fig. 187)	(f) at $-20°$ C.	9·1
,,	,, $-10°$ C.	10·2
,,	,, $-5°$ C.	10·8
,,	,, $0°$ C.	11·4
,,	,, $+10°$ C.	13·2
,,	,, $+20°$ C.	14·6
,,	,, $+30°$ C.	15·7
,,	,, $+40°$ C.	17·8
,,	(f_e) ,, $-5°$ C. (with additional ice load)	12·8

Sag of the power line ($f_{max.1}$) . at $+40°$ C. when the main line wire and one of the auxiliary wire ropes fail at one of the suspension points, assuming that the length of the catenary is thereby increased by $a = 6$ inches *

$$f_{max.1} = \sqrt{(f_{+40})^2 + \frac{3}{8}\,a\,.\,s} = \sqrt{17{\cdot}8^2 + \frac{3}{8} \times 6 \times 822} \quad = \quad 46{\cdot}5$$

(3 feet $10\frac{1}{2}$ inches)

Sag of the power line ($f_{max.2}$) . at $-5°$ C. with additional ice load, when the wires break in one of the neighbouring spans and the mast is deflected in the direction of the crossing span by an amount b, inches †

$$f_{max.2} = \sqrt{f_e^2 + \frac{3}{8} b \times s} = \sqrt{12{\cdot}8^2 + \frac{3}{8} \times 1{\cdot}7 \times 822} \quad = \quad 26{\cdot}3$$

Consequently $f_{max.1}$ is the sag to be dealt with (Fig. 186).

With the maximum sag $f_{max.1}$ the sag at the crossing point ($C = 120$ inches from the mast) between the power line and the postal line will be :

$$f_c = \frac{4 \times f_{max.1} \times C \times (s - C)}{s^2} = \frac{4 \times 46{\cdot}5 \times 120\,(822 - 120)}{(822)^2} \quad = \quad 23$$

* If this allowance seems open to question it should be confirmed by adding the necessary sketches and calculations.

† For the determination of b see below.

2. IN THE NEIGHBOURING SPANS.*

Span of the power line		360 feet (4,320 inches)
Sag of the power line, with a maximum stress of		17,200 lbs. per sq. inch
		Inches.
,,	at − 20° C.	100
,,	,, − 10° C.	105
,,	,, − 5° C.	108
,,	,, 0° C.	111
,,	,, + 10° C.	115
,,	,, + 20° C.	119
,,	,, + 30° C.	124
,,	,, + 40° C.	129
,,	,, − 5° C. (with additional ice load)	124

B. *Masts* (Figs. 186 and 189).

1. HEIGHT OF MAST.

	ft.	in.
From the ground to the uppermost telegraph wire	30	6
From uppermost telegraph line to guard wire †	3	3½
Sag (f_c) of the guard wire (as for the power line)	1	11
Height of guard wire suspension point above ground	35	8½
From guard wire to lowest power line	3	3½
	39	0
Height to lowest power line suspension point	say, 39	2½ (12 metres)
Height of topmost power line insulator from ground	42	6
Length of mast in the ground	6	6½
Gross length of mast to the uppermost insulator	49	0½

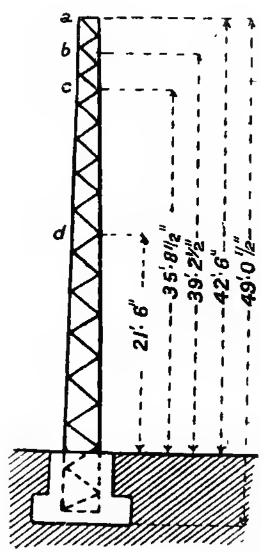


Fig. 188.

* It is assumed that the lengths and the tensions in the two neighbouring spans are alike.

† The regulations specify that an earthed guard wire or equivalent device is to be placed at least 1 metre (3 feet 3½ inches) below the lowest power line to avoid risk of postal wires being jerked up into contact with the H.T. lines when repairs are being carried out or when a postal wire snaps.

2. STRESSES IN THE MAST.

(*a*) Due to the Tension of the Power Lines and the Guard Line.*

Point of Action (see Fig. 188).	Forces due to:—	In the Crossing Span.					In the Neighbouring Spans.				
		No.	Cross-section (square inches).	Stress in lbs. per square inch.	Pull in lbs.	Bending Moment in lb.-inches.	No.	Cross-section in square inches.	Stress in lbs. per square inch.	Pull in lbs.	Bending Moment in lb.-inches.
a	Power line	1	·054	5,700	310	157,000	1	·039	17,200	660	340,000
b	Power lines	2	·054	5,700	620	288,000	2	·039	17,200	1,350	630,000
c	Guard wire	1	·031	5,700	176	76,000	1	·031	17,200	530	227,000
					1,106	521,000				2,540	1,197,000

(*b*) Due to Wind Pressure.

Point of Action (see Fig. 188).	Effective Mast Surface in square feet.	Wind † Pressure allowing 125 kg. per square meter (25·6 lbs. per square foot).	Bending Moment in lb.-inches.
d	Corner stays . . $39{\cdot}2 \times 2 \times {\cdot}3 = 23{\cdot}5$ Diagonals . . . $78{\cdot}4 \times {\cdot}75 \times {\cdot}13 = 7{\cdot}6$ 50 per cent. addition for the leeward side = 15·5 Cross-arms and insulators . . . . = 6 Total . . . . . 52·6 sq. feet	1,380 lbs.	355,000

From the above tables :—

		lbs.
Total line tension in the crossing span . .	$H_k =$	1,106
,, neighbouring spans .	$H_n =$	2,540
Wind pressure on mast	$H_w =$	1,380
Line tension reduced to the top of the pole, in the crossing span	$Z_k =$	1,030
Line tension reduced to the top of the pole, in neighbouring spans	$Z_n =$	2,320
		lb.-inches.
Bending moment in the crossing span . .	$M_k =$	521,000
Bending moment in the neighbouring spans .	$M_n =$	1,197,000
Difference moment‡	$M_n - M_k =$	676,000
Moment due to wind pressure	$M_w =$	355,000
Maximum moment§	$M_n - M_k + M_w =$	1,031,000

* It is assumed that the line is straight. For the calculation of the forces on masts at angle points see note on p. 191.

† The German regulations allow for a normal wind pressure of 125 kg. per square metre (25·6 lbs. per square foot approx.), but it is stated that on the sea coast or in specially windy districts a larger allowance may be necessary and should be employed.

‡ The greatest net pull is determined from the difference between the pulls in the crossing span and in the neighbouring span, but this should be at least equal to the pull in the crossing span itself. In many cases it pays to increase the pull in the crossing span artificially by using thicker wires, two guard wires, etc., so as to reduce the difference in pull in the two spans.

§ Even when M_k is greater than $M_n - M_k$, and has, therefore, to be used in the calculation, the full wind-pressure on the mast must be allowed for.

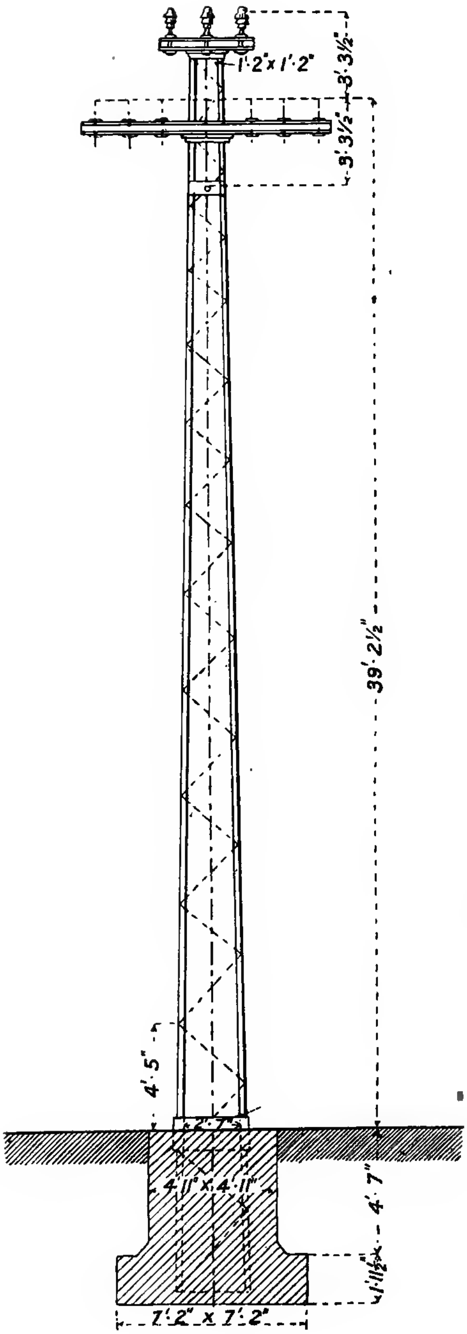


Fig. 189.

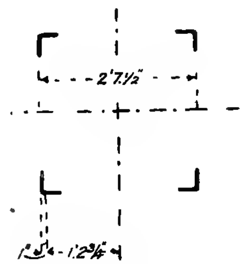


Fig. 190.

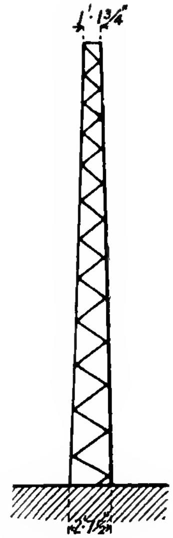


Fig. 191.

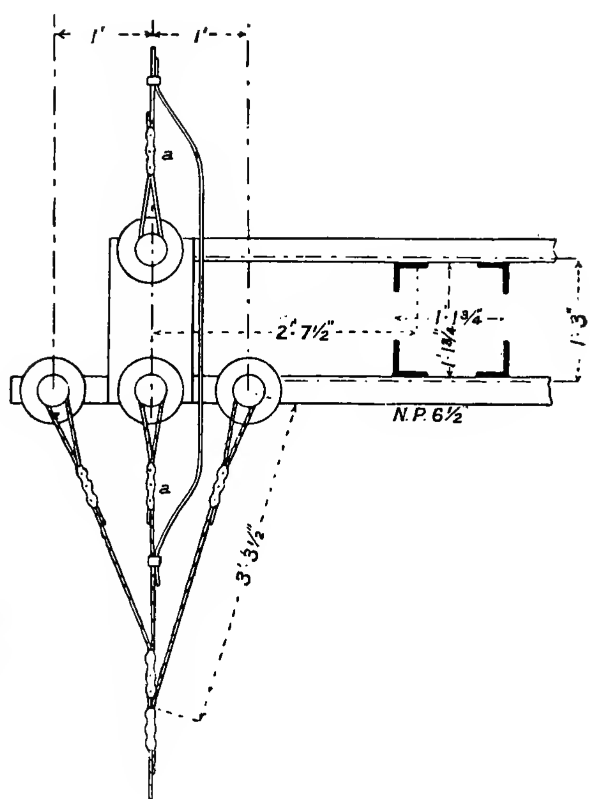


Fig. 192.

3. STRENGTH OF MAST.

(*a*) *At the lowest point on the angle iron stays* (see Fig. 190) :—

	inches.
Section of angle iron	$3\frac{1}{2} \times 3\frac{1}{2} \times \cdot 425$
Distance of centre of gravity from neutral axis	$\xi \doteq 1$
$J_{\text{min.}}$	1·38 inches.[4]
	sq. inches.
Gross cross-section	$Q = 2{\cdot}9$
Section weakened by two rivets ($\frac{5}{8}''$ diameter)	$q = 2{\cdot}35$
	lbs.
Weight of mast	$g = 2{,}860$

Compressive force $S_d = \frac{1}{4}\left(\frac{M_{\text{max.}}}{e} + g\right) = \frac{1}{4}\left(\frac{1{,}031{,}000}{14\frac{3}{4}} + 2{,}860\right)$. $= 18{,}000$

Tensile force $S_z = \frac{1}{4}\left(\frac{M_{\text{max.}}}{e} - g\right) = \frac{1}{4}\left(\frac{1{,}031{,}000}{14\frac{3}{4}} - 2{,}860\right)$. $= 16{,}600$

factor.

Factor of safety as regards compression :

$$n_d = \frac{k \times Q}{S_d} = \frac{57{,}000 \times 2{\cdot}9}{18{,}000} = 9{\cdot}25^*$$

Factor of safety as regards tension :

$$n_z = \frac{k \times q}{S_z} = \frac{57{,}000 \times 2{\cdot}35}{16{,}600} = 8{\cdot}1$$

Factor of safety as regards lateral bending * (collapse) :

$$n_k = \frac{E \times J_{\text{min.}}}{S_d \times l^2} = \frac{30{\cdot}7 \times 10^6 \times 1{\cdot}38}{18{,}000 \times 53^2} = 8{\cdot}3$$

l being the free length between diagonals in inches (see Fig. 189).

(*b*) *At the lowest diagonal* :—

	inches.
Section of diagonal angle iron	$= 2\frac{3}{8} \times 1\frac{9}{16} \times \cdot 2$
$J_{\text{min.}}$	$= \cdot 088$ inches.[4]
	sq. inch.
Gross cross-section	$= \cdot 75$
Net section weakened by one $\frac{5}{8}$ inch rivet	$= \cdot 62$

Load on one diagonal inclined at an angle of 45° :

lbs.

$$= D = \tfrac{1}{2}(H_n - H_k + H_w) \times \sqrt{2} \qquad = 1{,}980$$

Factor of safety as regards tension :

factor.

$$n_z = \frac{k \times q}{D} = \frac{57{,}000 \times \cdot 62}{1{,}980} = 18$$

Factor of safety as regards lateral bending † (collapse) :

$$n_k = \frac{J_{\text{min.}} \times E}{D \times l^2} = \frac{\cdot 088 \times 30{\cdot}7 \times 10^6}{1{,}980 \times (39\frac{1}{2})^2} = 8{\cdot}8$$

* The structure is considered sufficiently safe if the separate loads show a factor of safety of at least 5.

† Even when the diagonals are staggered the whole distance between neighbouring diagonals in one plane should be employed and the minimum moment of inertia should be used.

Factor of safety of the rivet against shearing:

$$n_s = \frac{k \times \frac{\pi d^2}{4}}{D} = \frac{57{,}000 \times \cdot 305}{1{,}980} \qquad = 8 \cdot 8$$

(*c*) *Deflection of the mast when the wires break in one of the neighbouring spans* :—

(For dimensions of the angle iron, see above under B, 3 (*a*).

Distance of centre of gravity from neutral axis . $= e = \frac{31\frac{1}{2} + 13\frac{3}{4}}{2 \times 2} - 1$ inches.

(See Fig. 191) . . . . $= 10 \cdot 25$

Moment of inertia half-way up the mast . . $= J = 4\,(J_{\min.} + Q \times e^2)$

$$= 4\,(1 \cdot 38 + 2 \cdot 9 \times (10 \cdot 25)^2) = 1{,}230 \text{ inch.}^4$$

(Note.—$J_{\min.}$ must be used rather than J_ξ as the latter gives too small a deflection.)

$$b = \frac{Z_b \times L^3}{3 \times E \times J} = \frac{1{,}805^* \times (470\frac{1}{2})^3}{3 \times 30 \cdot 7 \times 10^6 \times 1{,}230} \qquad \begin{array}{r}\text{inches.}\\ = 1 \cdot 7\end{array}$$

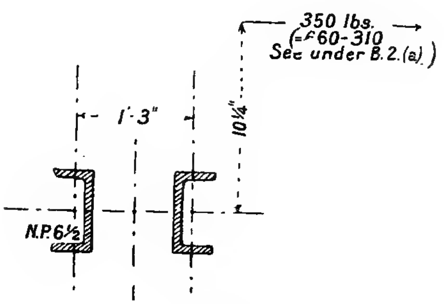


Fig. 193.

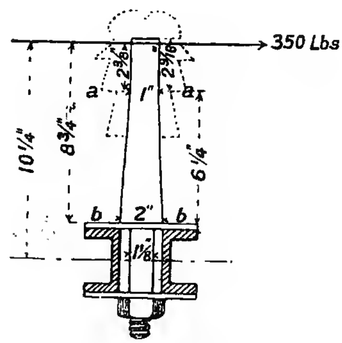


Fig. 194.

(*d*) *Stability of the mast* (Fig. 189) :—

Weight of concrete foundation block †

$$= \frac{(59 \times 59 \times 55) + (86 \times 86 \times 23\frac{1}{2})}{1{,}728} \times 128 \qquad \begin{array}{r}\text{lbs.}\\ = 27{,}200\end{array}$$

Weight of earth resting on the ledges

$$= (86^2 - 59^2)\,55 \times 96 \qquad = 11{,}800$$

Weight of mast $= 2{,}860$

Total weight $= G = 41{,}860$

* This figure of 1,805 lbs. is obtained as follows :—When the wires break in one of the neighbouring spans the mast is deflected towards the crossing span by a force equal to $Z_n - Z_k$ plus the (diminished) tension in the wires of the crossing span. This crossing span tension may be considered as having been halved due to the deflection and consequent increase in sag. The total deflecting force is

$$\therefore \quad = Z_b = Z_n - Z_k + \frac{Z_k}{2} = Z_n - \frac{Z_k}{2} = 2{,}320 - 515 = 1{,}805.$$

† The weight of concrete is to be taken as not more than 128 lbs. per cubic foot and that of earth as not more than 102 lbs. per cubic foot.

Distance of point of action of earth pressure from the edge of the foundation block

$$= y = \text{half-width of foundation block} - \frac{M_{\text{max.}} \times \dfrac{49\text{ ft. }0\tfrac{1}{2}\text{ in.}}{42\text{ ft. }6\text{ in.}}}{G}$$

(the ratio $\dfrac{49\text{ ft. }0\frac{1}{2}\text{ in.}}{42\text{ ft. }6\text{ in.}}$ being used in order to obtain the moment with regard to the base of the foundation from the moment with regard to the ground level)

$$\therefore\ y = 43 - \frac{1{,}031{,}000 \times \dfrac{49\text{ ft. }0\tfrac{1}{2}\text{ in.}}{42\text{ ft. }6\text{ in.}}}{41{,}860} = 14{\cdot}8 \text{ inches.}$$

Pressure at outer edge of foundation block

$$p_k = \tfrac{2}{3}\frac{G}{14{\cdot}8 \times 86} = \tfrac{2}{3}\frac{41{,}860}{14{\cdot}8 \times 86} = 22 \text{ lbs. per square inch.}$$

C. Cross-Arms and Insulator Pins.

(*a*) *Cross-arms* (Figs. 192 and 193) :—

Cross-section of the channel iron $= q = 1{\cdot}4$ square inch.

Moment of resistance $= W_x = 1{\cdot}07$ inch.^{3}

The tension H_l of one wire produces a tensile or compressive force on the two channel irons, respectively, of

$$k = \frac{H_l \times l}{\text{Distance of centre of gravity}} = \frac{350 \times 31\frac{1}{2}}{15} = 730 \text{ lbs.}$$

Besides this a twisting moment $M_d = 350 \times 10\frac{1}{4}$ (see Fig. 193) acting at the end of an arm $l = 31\frac{1}{2}$ inches has to be withstood by the two channel irons at the section $a - a$ (Fig. 192). This produces a bending moment in each channel iron :

$$= M_b = \frac{M_d \times l}{\text{Distance of centre of gravity}} = \frac{350 \times 10\frac{1}{4} \times 31\frac{1}{2}}{15} = 7{,}500 \text{ lb.-inches.}$$

The stress on one channel iron is therefore

$$K = \frac{k}{q} + \frac{M_b}{W_x} = \frac{730}{1{\cdot}4} + \frac{7{,}500}{1{\cdot}07} = 7{,}520 \text{ lbs. per square inch.}$$

(*b*) *Insulator Pins* (Fig. 194) :—

Maximum pull* $= 350$ lbs.

Moment M at the section $a - a = 350 \times 2\frac{3}{8} = 830$ lb.-inches.

The 1-inch diameter pin has a resisting moment W of ·105 inch.^{3}

$$\therefore \text{ Bending stress} = K = \frac{M}{W} = \frac{830}{\cdot 105} = 7{,}900 \text{ lbs. per square inch.}$$

The compressive and tensile force at the section $b - b$ ($1\frac{1}{8}$ inch in diameter) is $\pm \dfrac{350 \times 8\frac{3}{4}}{e}$, where e is the distance of the centre of gravity of half the bedding surface from the centre of the bolt, or

* This assumes that the wires in both the crossing span and the neighbouring span are strained to the same insulator. If they are connected to separate insulators as shown in Fig. 192 it is sufficient to consider only the pull in the crossing span.

$$e = \frac{4}{3\pi} \times \frac{1^2 + (1 \times \frac{9}{16}) + (\frac{9}{16})^2}{1 + \frac{9}{16}}$$
$$= {\cdot}51 \text{ inch.}$$

$$\therefore \text{ Compressive (or tensile) force} = \pm \frac{350 \times 8\frac{3}{4}}{{\cdot}51} = \overset{\text{lbs.}}{6{,}000}$$

The cross-section of half the annular contact face at $b - b$ is

$$\frac{F}{2} = \frac{\pi}{4}(2^2 - 1\tfrac{1}{8}^2) \times \tfrac{1}{2} = 1{\cdot}07 \text{ square inch.}$$

$$\therefore \text{ Compressive stress at } b - b = \frac{6{,}000}{1{\cdot}07} = 5{,}600 \text{ lbs. per square inch.}$$

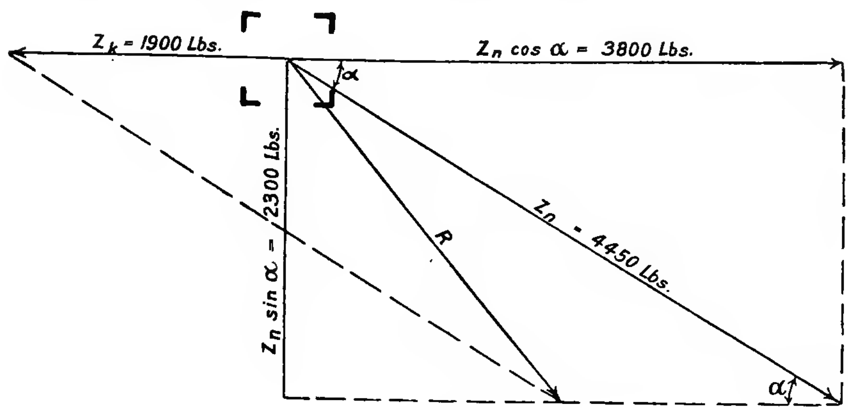


Fig. 195.

The maximum tensile stress in the $1\frac{1}{8}$ inch diameter bolt having a cross-section at the bottom of the thread of ·7 square inch is $\frac{6{,}000}{{\cdot}7} = 8{,}600$ lbs. per square inch, giving a factor of safety of $\frac{57{,}000}{8{,}600} = 6{\cdot}65$.

In order to simplify the calculations under II., A and B, the following tabulated results can be used :—

A. Sag of the Line.

Meaning of the Symbols.

s = Length of span of the power line in inches.

f_{-20} = Sag of the power line at — 20° C.

$f_{\max.1} = \sqrt{(f_{+40})^2 + \frac{3}{8} a \times s}$ = sag of the power line in inches at + 40° C. when the main wire and one of the auxiliary supporting wires give way and thus lengthen the catenary by a = 6 inches.

f_e = Sag of the power line at — 5° C. with additional ice load.

TABLE 34.*—*Values of the Sag at various Temperatures and for various lengths of Span.*

s	f_{-20}	f_{-10}	f_{-5}	f_{-0}	f_{+10}	f_{+20}	f_{+30}	f_{+40}	$f_{max\,1}$	f_e
400 inches.	1·6	2	2·35	2·95	4	4·95	5·9	6·7	30·5	3·55
and so on.										
1,375	31·6	33	34·5	35	37	39	41	42·5	70	36·5
1,425	33·5	35·5	36·2	37	39·5	41	43	45	72	38·5
and so on.										

This table should be filled in completely so that the sag at any temperature can be read off at once. For the neighbouring spans a separate calculation can be made in each case or a curve can be used.

* The numbers inserted in this and the following tables are only intended as a guide and do not refer to the example just worked through.

B. Mast Height and Mast Stresses.

Table 35.

Meaning of the Symbols.

$f_{\max 2} = \sqrt{(f_c)^2 + \frac{3}{8} b \times s}$ = sag of the line in inches at $-5°$ C. with additional ice load when the wires in one of the neighbouring spans break and mast deflects towards the crossing span by an amount b inches.

$f_c = \frac{4 f_{\max 1} \times c\,(s - c)}{s^2}$ = maximum sag in inches at the crossing point situated c inches from the mast.

h = the necessary minimum height of mast in inches measured up to the supporting point of the highest power line. This is determined from the height of the uppermost postal wire, the allowance of 2 metres between that and the lowest power line, the sag f_c, the separation of the various power lines from one another, the height of the line supports above the top of the mast, and any difference in level which may exist between the foot of the mast and the foot of the telegraph pole.

q = cross-section of power line in square inches.

p = greatest tensile stress in the line in lbs. per square inch.

H_e = pull of the lines acting in any one plane in lbs.

$\left.\begin{array}{l} H_k \\ H_n \end{array}\right\}$ = sum of all the pulls H_e in lbs.

l = distance of the average point of action of the forces H_e from the top of the mast in inches (+ if above the top of the mast and — if below it).

$\left.\begin{array}{l} Z_k \\ Z_n \end{array}\right\}$ = total force in the crossing span or neighbouring span reduced to the height of the top of the mast, in lbs.

Z_{n-k} = difference of the top pulls in lbs.

R = resultant of Z_n and Z_k in lbs. for masts at corner points.

$Z_{\max.}$ = the pull in lbs. used in the calculation of the mast.

L = height of mast measured to the top of the main corner stays in inches.

$b = \frac{Z_b{}^* \times L^3}{3 \times E \times J}$ = deflection of the mast in inches when all the wires in one of the neighbouring spans break.

* Note.—See note on p. 185 for explanation of Z_b.

Table

Drawing No.	Crossing No.	s	f_{max_2}	c	f_e	h	Crossing Span.						
							No. of Lines.	q	p	H_e	H_k	l	Z_k
1	I. and II.	1,375	56	236	40	275 + 78 + 40 = 393	2 H.T. lines 5 ,, ,, 2 ,, ,, 1 Guard ,,	·054 ·054 ·054 ·031	5,700 5,700 5,700 5,700	620 620 620 180	2,040	— 35	1,880
2	III.	1,425	57·5	196	35	255 + 78 + 35 = 368	,,	,,	,,	,,	,,	,,	,,

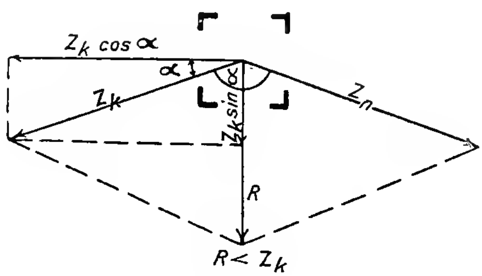


Fig. 196.

36.

Neighbouring Span.							$Z_n - Z_k$	R*	$Z_{max.}$	Type of Mast.	L	b
No. of Lines.	q	p	H_e	H_n	l	Z_n						
2 H.T. 2 H.T. 2 H.T.	·039 ·039 ·039	20 000 20,000 20,000	1,560 1,560 1,560	4,680	− 23	4,400	2,520	—	2,520	$\frac{1,300}{12}$	470	3·4
”	”	”	”	”	”	”	”	Left-hand Mast 4 200 Right-hand Mast 2,650	Left-hand Mast 4.200 Right-hand Mast 2,605	$\frac{2,000}{12}$ $\frac{1,300}{12}$	470 470	1·85 3·4

* Determination of R:—

In order to determine the effective pull at the top of the mast in such a case as Fig. 195 the actual pull (Z_n) in the neighbouring span is resolved into two components at right angles to one another and lying in the directions of the main horizontal axes of the mast. The net pull on the top of the mast is then $Z_n \sin \alpha + Z_n \cos \alpha - Z_k = 2{,}300 + 3{,}800 - 1{,}900 = 4{,}200$ lbs. In general the pull to be used is the greatest of the three values: Z_k or $Z_n \sin \alpha + Z_k - Z_n \cos \alpha$ or $Z_n \sin \alpha - Z_k + Z_n \cos \alpha$. That forces at right angles are directly added together is due to the quadrangular form of the mast. If desired, however, the actual resultant force R can be used, but the mast must then be so turned that one of its main axes coincides with the direction of R, and if R is then smaller than $Z_k \cos \alpha + Z_k \sin \alpha$ (Fig. 196) the latter value must be used.

C. Static Calculation of the Mast.

Table 37a.

Meaning of the Symbols (see Fig. 197).

L = gross length of mast above the ground in inches.

v = length of the upper and lower halves of the mast in inches.

W = wind pressure on the mast, cross-arms and insulators in lbs. calculated on the assumption of 25·6 lbs. per square foot of flat normal surface and making an addition of 50 per cent. of the front (windward) surface to allow for the back (leeward) surface.

h_w = height of point of action of the wind above the ground in inches.

g = weight of the upper and lower halves of the mast in lbs.

B_1 and B_2 = outside width of the top and bottom of the mast (or half-mast) in inches.

r = separation of the rivet holes at B_1 in inches (see Fig. 197).

h_k = maximum allowable free length of one of the angle iron corner stays in inches (as regards collapse under lateral bending action).

d = maximum allowable free length of diagonal in inches.

h_o = length of mast foot below ground in inches.

$M_{max.}$ = maximum moment at the ground level, or point of fixture to the foundation, in lb.-inches.

F_{net} = net cross-section of the angle iron where weakened by the rivet holes in square inches.

e = distance of the centre of figure of the angle iron stays from the central axis of the mast in inches.

$S_z = +\frac{M_{max}}{4e} - \frac{g}{4}$ = tensile load on one angle iron in lbs.

$S_d = -\frac{M_{max}}{4e} - \frac{g}{4}$ = compressive load on one angle iron in lbs.

K = stress in the material in lbs. per square inch.

s = factor of safety of one angle iron = $\frac{30{\cdot}7 \times 10^3 \times J_{min.}}{S_d \times l^2}$.

B_m = mean outside breadth of the mast (upper or lower half) in inches.

$J_m = 4\,(J_{min.} + Q \times e^2)$ = moment of inertia of the cross-section of the mast in inches.[4]

$\frac{Z + W}{2}$ = total horizontal force acting on one mast face in lbs.

$D = \frac{Z + W}{2} \times \sqrt{2}$ = load in lbs. on the diagonals, assuming that the angle irons are parallel and that the diagonals are inclined at 45°.

Type of Mast.	L	l	W	h_w	g	B_1	B_2	r	h_k	d	h_o	$M_{\text{max.}}$	Angle iron Section.	$F_{\text{net.}}$	$J_{\text{min.}}$	e	S_z	S_d	K	s	B_m	J_m
												1. *Mast for a Top Pull* $Z = 2{,}850$ *lbs.*										
1,300 / 12	470	235 / 235	660 / 770	117·5 / 117·5	1,100 / 1,330	22 / 31·5	12·5 / 22	18·5 / 27	40 / 58	38	79	2,850 × 235 + 660 × 117·5 = 747,000 lb.-inch. / 2,850 × 470 + 660 × 352·5 + 770 × 117·5 = 1,661,000 lb.-inch.	$3\frac{3}{16}'' \times 3\frac{3}{16}'' \times \frac{5}{16}''$ / $4'' \times 4'' \times \cdot 4''$	4 / 6·3	·71 / 1·77	10·2 / 14·6	+ 18 500 / + 28,000	− 19,000 / − 29,300	11,700 / 11,400	7·15 / 5·42	18·25 / 26·75	465 / 1,800
1 300 / 12½												and so on.										

2. *Mast for a Top Pull* $Z = 4{,}450$ *lbs.*
and so on.

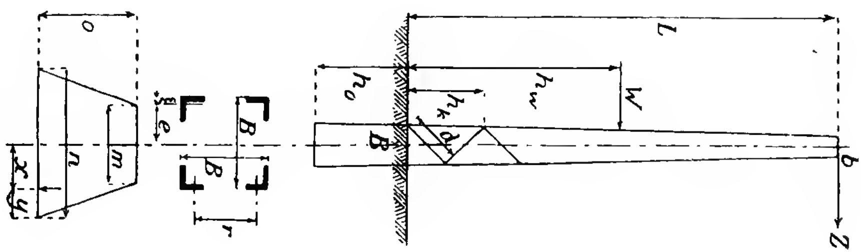


Fig. 197.

C. Static Calculation of the Mast (continued).

Table 37b.

Meaning of the Symbols.

K_d = stress on the material of the diagonals in lbs. per square inch.

s_d = factor of safety of the diagonals against collapse through lateral bending.

K_{sh} = shearing stress on the rivets used to fix the diagonals in lbs. per square inch.

m = breadth of the (square) top of the foundation block in inches.

n = breadth of the (square) bottom of the foundation block in inches.

o = depth of the foundation block in inches.

$M_\sigma = M_{\text{max.}} + (Z + W) \times o$ = moment acting on the base of the foundation block in lb.-inches.

G_F = weight of the foundation block of rammed concrete (allowing not over 128 lbs. to the cubic foot) in lbs.

G_E = weight of the soil vertically over the foundation ledges in lbs. (allowing not over 102 lbs. to the cubic foot).

G_M = weight of mast in lbs.

G = sum of G_F, G_E, and G_M.

$x = \dfrac{M_\sigma}{G}$.

$y = \dfrac{n}{2} - x$.

$P_k = \dfrac{2G}{3y \times n}$ = edge pressure in lbs. per square inch.

Type of Mast.	$\frac{Z+W}{2}$	D	Section of the Diagonals.	$F_{\text{net.}}$	$J_{\text{min.}}$	K_d	s_d	Diameter of Rivets.	Cross-section of Rivets.	K_{sh}	m	n	o	M_σ	G_F	G_E	G_M	G	x	y	p_k
	1. *Mast for a Top Pull of* $Z = 2{,}850$ *lbs.*																				
$\frac{1{,}300}{12}$	2,150	3,050	$1\frac{3}{4}'' \times 1\frac{3}{4}'' \times \cdot 2''$	·54	·078	5,650	5·28	$\frac{5}{8}''$	·31	9,800	$39\frac{1}{2}$	98	86	$2{\cdot}05 \times 10^6$	30,000	23,300	2,700	56,000	37	12	30·7
$\frac{1{,}300}{12{\cdot}5}$																					

and so on.

2. *Mast for a Top Pull of* $Z = 4{,}450$ *lbs.*

and so on.

Special Safety Suspension Arrangements.—Overhead power lines which approach roads carrying heavy traffic so closely as to be a source of danger to

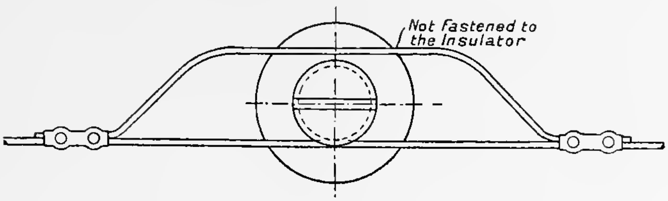


Fig. 198.

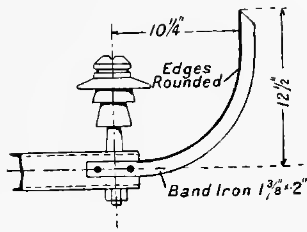


Fig. 199.

persons when a wire falls should be specially amply designed in every part so as to give a greater factor of safety than usual. These requirements will be complied with if the stresses are reduced by about half, if the distance between masts is

Fig. 200.

diminished, and if factors of safety of $3\frac{1}{2}$ to 4 are arranged for in all the component parts.

In addition the risk of wires falling should be further reduced by the use

of safety loops at the insulators (Fig. 198) and hoop guards (Figs. 199 and 200). The former hold the wire together even after a burn-out or weakening has occurred at an insulator. Hoop guards are also used at corner points, even when no special safety is demanded, so as to prevent wires falling when an insulator is destroyed. A safer plan, however, is to make all corner masts into strain masts and to use duplicate insulators.

As in the case of earthing bows, the hoop guards must also be dimensioned so that the perching of birds on them cannot cause short circuits. The hoops should be fixed with two screws so as to prevent them twisting and causing contact to earth.

Increased safety with suspension insulators need only be ensured for road, rail, and postal wire crossings. The best, but also the most expensive arrangement, consists in carrying the wires across in an ironwork bridge structure. In practice, however, sufficient security can be more simply attained by employing duplicate chains of insulators for each end of each line. The duplicate insulators are connected at the lower end by a cross-piece which carries a terminal at its centre, to which the line is attached in such a way that even if the screws should loosen the wire could not fall. The cross-piece is connected to the insulators by ball and socket joints so that it can set itself in any position under lateral tension.

17. ERECTION OF POLES AND MASTS.

Excavation Work.—It is false economy to make the pole excavation too small. The workman must have ample room to use shovel and pick if the work is to proceed rapidly and smoothly. For wooden poles the hole is usually made 5 to 7 feet deep and 18 or 20 inches wide. The longitudinal section is stepped as shown in Fig. 201. The lowest step serves for the workman to stand on whilst excavating the lower part of the hole. In ordinary soil the bottom of a 7-foot hole cannot be made much less than 27 $\times$ 27 inches.

If the earth is easy to work but not firm it is usual to make several steps on that side of the hole from which the pole is going to be put in (Fig. 202). The

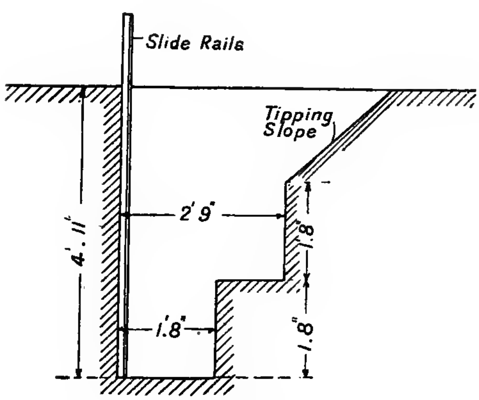


Fig. 201.

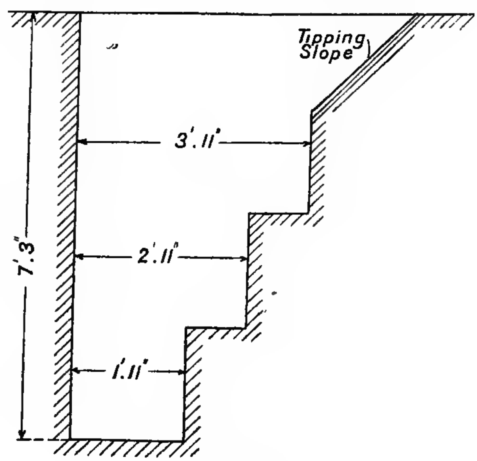


Fig. 202.

number of steps and the expansion of the opening towards the top must be increased with increasing instability of soil. In particularly bad cases the stepping process will have to be carried out on all sides. When water is present the hole must be lined or be carried out with the aid of the caisson shown in Fig. 203. This is made of $1\frac{1}{2}$ or 2 inch boards, preferably placed horizontally, bound together by vertical angle pieces. The earth, generally loose sand, is drawn up by means of a bucket and rope. Holes in wet soil are only partially prepared beforehand and then finished off at the time the pole is actually erected. When concrete work has to be carried out the water is drawn off by means of a pump whose suction pipe reaches into a special sump arranged near the mast hole.

In ground free from stones and not too dry (loamy agricultural land) the holes for the smaller poles can conveniently be drilled out. This is rather quicker

than hand labour, and at the same time the stability of the poles is increased, as they are surrounded on all sides with undisturbed soil. The method is only applicable to small, light masts which can be lifted bodily and let into the hole vertically.

In rocky ground the holes are made with pick and crowbar or else they are blasted out. For the latter process a hole is bored with a rockdrill about 10 or 12 inches deep and into this blasting powder or a cartridge is placed and covered with dry sand. The charge is exploded by means of a pair of wires and a shot-firing set. The wires must be long enough to place the operator outside the danger zone, and the space between the operator and the charge must be clear and open to observation.

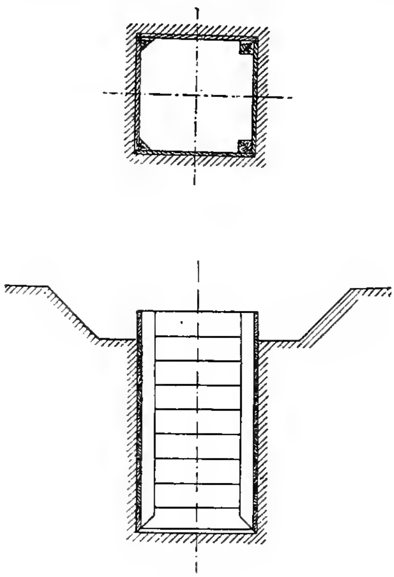


Fig. 203.

Carriage and Erection of the Masts.—Wooden poles and light masts can be unloaded from the trucks by rolling or sliding them along a platform connecting the truck and the cart. The rolling is controlled by guide ropes slung round the upper and lower ends of the pole. The space to be traversed by the pole should be kept clear of people so as to avoid accidents in case a rope breaks and the platform shifts. Heavy strain masts and corner masts should be shifted by means of chain and pulley if no crane is available. When a number of masts have to be dealt with it pays to erect a derrick hand crane. Most railway companies possess travelling cranes for hand operation. These can be hired at a small charge and greatly facilitate the unloading. Masts should never be thrown off the trucks, as damage almost always results.

The masts should be labelled to correspond with the route-marking pegs, and they should be delivered in the proper order in accordance with these markings. The route map should also contain full particulars as to the position of the various masts.

In the transportation of lattice-work towers or masts care must be taken not to bend or damage the diagonals or stays. Square lattice masts intended as intermediate or supporting masts only, and therefore of light cross-section, require special care. The ends must not be left free to swing about, as this would easily cause damage to the light angle iron stays.

Wooden poles of ordinary length can be carried to the erection spot by the erecting gang, consisting in this case of four or five men. Iron masts are usually carried on a two-wheel trolley, which should have broad-rimmed wheels, as it will often be used on bad field paths or agricultural land.

The raising of iron masts is carried out by means of ladders or by lifting struts—*i.e.*, two poles coupled together near the top with rope (see Fig. 204).

Fig. 204.

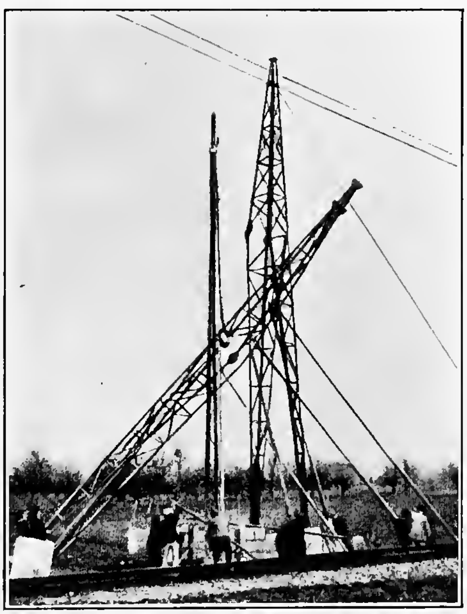


Fig. 205

The mast is brought up on the trolley to the foundation hole in such a position that the foot rests against the sliding boards or rails placed against the back of the hole (see Fig. 201). The head of the pole is then tipped up until a short pair of lifting struts or a ladder can be introduced. This enables the pole to be still further raised, and a longer ladder can be brought into use and so on until the mast has been set vertical. The formation of a tipping slope (see Figs. 201 and 202) at the mouth of the hole is a decided help. Heavy masts are best erected by the aid of a windlass. The latter must be attached at a point above the centre of gravity of the mast and on the mast axis. The bottom of the

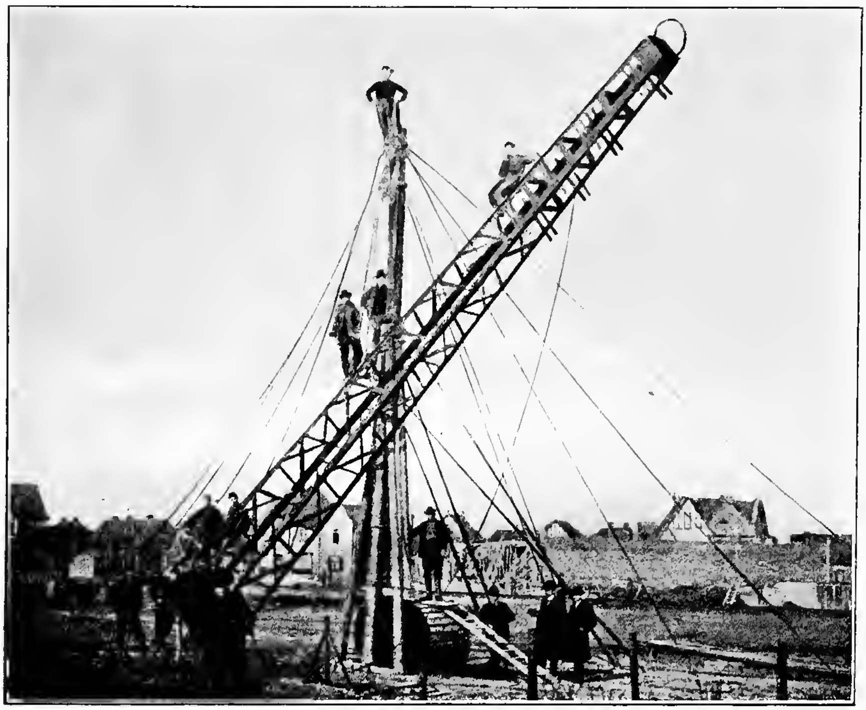


Fig. 206.

mast (with a board in between so as to distribute the force over a number of diagonals) rests against a strong beam braced to the windlass at its other end. On soft ground the windlass must be suitably packed up. The use of a windlass does not do away with the need for lifting struts, as these are still wanted for guiding and supplementary work.

Wooden poles can be erected either with lifting struts or with single struts fitted with forked ends (pole lifters) each operated by one man. At least three such forks are required, of which each pair in turn holds the mast in equilibrium.

The difficulty of erecting a mast increases much more rapidly with its length than with its weight. Masts more than about 50 feet high cannot be erected in the

above-described manner. For these a derrick or similar erection with hand crane is necessary (see Figs. 205 and 206).

This will serve to raise them to a certain height, and the final erection can be carried out by means of other cranes or pulley blocks attached to trees or anchored by means of stays at suitable points.

When the masts are to be erected on a finished foundation block and held by foundation bolts the difficulty is somewhat greater (see Fig. 206). In order to pass the foundation bolts more easily the mast is first set on wooden blocks somewhat higher than the tops of the bolts, and whilst the adjustment is being completed the mast is held by guy ropes previously attached. In the case of the largest masts it is advisable to provide them with hinged feet (see Fig. 113).

Strain masts or corner masts which have to stand one-sided loads are given a rake or set, *i.e.*, their vertical axes are deflected a certain amount in the direction opposite to that of the pull. The deflection of a mast usually amounts to about 2 per cent. of the free length, and the rake is made equal to about half this amount. It is not advisable to compensate by rake for the maximum deflection, because the latter only occurs occasionally and for short intervals.

If concrete foundations are to be used to improve the stability of a mast the ground should be covered with a layer of well-rammed concrete, 6 or 8 inches deep, before placing the masts in position.

Cross-arms and insulators are usually mounted before erecting the mast, unless their weight is likely to add appreciably to the trouble of erection

18. ERECTING THE WIRE.

In view of their great importance at the present time, overhead transmission lines must possess a far greater degree of reliability than was necessary in the early days of electrical supply, and consequently much more exact and careful constructional work is demanded. The old-time erector only knew the dynamometer by name, the sag obtained was a matter of indifference, and the straining-up of the wire ceased when it appeared taut.

The manufactured length of bare solid copper wire depends on the cross-section. Usually a copper ingot weighing about 175 lbs. is employed, so that a single coil of wire ·14 inch in diameter (·0155 square inch in area) would have a length of 900 to 1,000 yards. Stranded cables made up of wires of smaller section than this would have a correspondingly greater length. Thus a seven-strand cable having a total cross-section of ·054 square inch could be delivered in lengths of 1,900 to 2,000 yards. The weight of such a coil would be about 1,250 lbs., or, say, 12 cwt. with the drum. Greater weights than this are not convenient for transport and handling. If greater weights are insisted upon either ingots of greater size must be used—and this is not possible in all factories—or else several normal lengths will have to be joined together. This is effected by soldering and subsequent hammering of the joint to harden it. The individual soldered joints are distributed over several yards of cable, so that the strength is hardly affected at all. Joints in one or more wires also become necessary if a break occurs on the stranding machine.

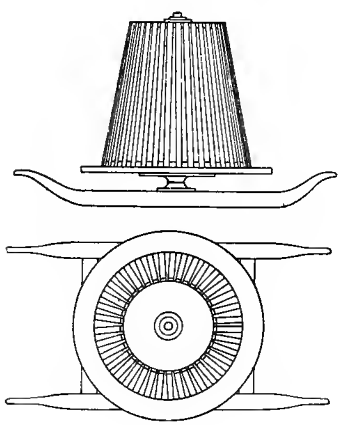


Fig. 207.

Faults must be looked for as the cable is unwound from the drum. These may take the form of a single joint of the whole of the wires at one point, meaning a weakening of the cable, or single wires inside the cable may here and there be simply twisted together instead of being soldered. In a particular case, for instance, a nineteen-strand cable of ·08 square inch cross-section was found to have the inner wire twisted together at several points, and in order to make room for the twist the second layer of six wires had been cut away for a short distance.

Wire coils should be placed on a turntable (Fig. 207) and be unwound by drawing at the outside end. A simple brake arrangement prevents over-running. If no turntable is available care must be taken to unwind in the manner shown in Fig. 208, and never as in Fig. 209, as the latter permits loops and kinks to

form. Any kinks or other faulty points which may occur accidentally should be cut out.

When cable has to be unwound from a drum the latter is provided with a spindle supported horizontally on V blocks. Small drums are sometimes mounted on an arrangement like a turntable with a vertical spindle. Over-running is prevented by a brake. The unwinding is carried out by a number of labourers

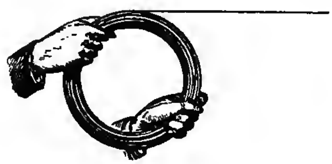


Fig. 208.

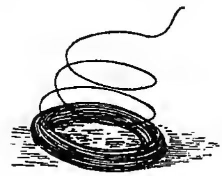


Fig. 209.

or, in the case of cables of greater section and length, by horses. Wires must not be drawn along roads or stony ground, as the hard outer skin may be damaged and the tensile strength diminished. At road crossings the wire should be carried on rollers or pulleys (Figs. 210 and 211) placed at such a height as to clear the traffic. Rollers should also be used, mounted on the cross-arms of the masts, whenever the masts are stiff enough to withstand the tension involved in drawing the wire along. This greatly reduces the damage done to the land through the tramping

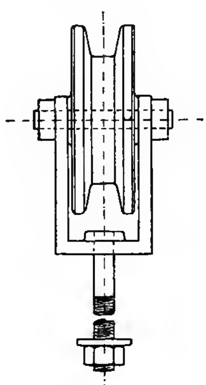


Fig. 210.

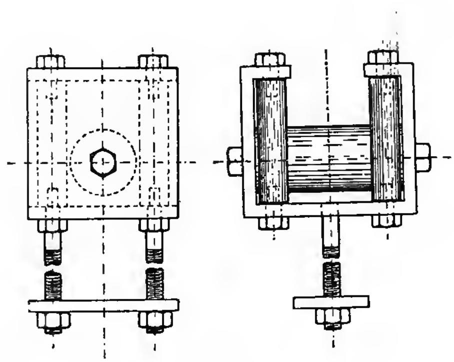


Fig. 211.

of men and horses to and fro. If the masts are not strong enough for the purpose the rollers should only be raised above the earth sufficiently to keep the wire from rubbing on the ground.

The cable drum should be placed so far from the first mast that the wire approaches the mast at an angle of at least 45°.

A rope is first passed over the mast with the aid of a pole, and to the end of this rope the wire is attached and so drawn over the mast. The rollers prevent the wire from falling off as well as protecting it from damage and easing the motion.

With aluminium wire this is the only allowable method. The softness of the metal makes it unsafe to drag it over the surface of even soft soil. When suspension insulators are employed the difficulties of erection are increased because of the greater overhang of the cross-arms and the large gap between the line and the cross-arm.

The work is simplified if it is possible to shift the chains of the insulators on the cross-arms. In this case the line is drawn over rollers fixed to the mast (see Fig. 212) and is given the correct tension. Then the insulator chain is brought immed'ately over the line and clamped to it, and finally the insulator with the line is moved to its proper position at the end of the arm.

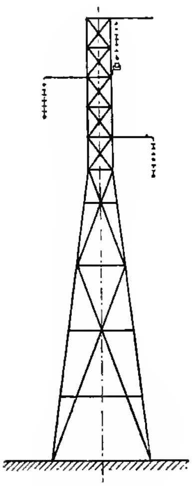


Fig. 212.

Lines of small section and small span can be laid out flat along the ground and raised on to the masts by means of poles or by climbing up the mast. Larger sizes, especially if the spans are long, require pulley blocks to raise them into position (a 500-foot span of ·054 square inch copper cable weighs about 1 cwt.). When gripping the wire to raise it care must be taken not to nick it.

Aluminium lines are easier to handle as far as weight is concerned, but they require more care than copper ones.

In straining-up wires pulley blocks are used or, in the case of long spans, windlasses with large drums to accommodate a considerable length of rope are employed, fixed at the foot of a mast.

The wire must be gripped by a clamp (Fig. 213) whose jaws are of the same material as the wire and which grips a length of wire equal to 12 or 15 diameters.

Stretching screws (turn-buckles) or ratchets fitted with a spring balance (dynamometer) are used for adjusting the tension in the wire exactly. These are attached to the insulator pin or to the cross-arm. Draw tongs, giving a parallel grip for all sections of wire, are a useful additional tool.

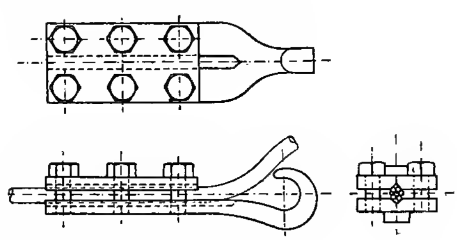


Fig. 213.

Having drawn up the wire with the pulley block, the draw tongs, with the spring balance attached, are applied to the wire and the tension is tried. If this is found to be approximately correct the spring balance is left in position and the exact adjustment is carried out by screwing the stretching screw in or out. When the supporting points of the line are at different levels the dynamometer should be inserted at the higher level.

During the adjustment the wire should be lying on the rollers, which will be clamped to the cross-arm close to the insulator pin. Sometimes the rollers are provided with pins corresponding to those of the insulators so that they can temporarily take the place of the latter.

Owing to the small friction at the rollers the tension in a whole set of neighbouring spans will automatically adjust itself to the same value, so that the checking of the tension by spring balance need not be carried out at each span, but only once between each pair of strain masts.

When a twin-core telephone cable has to be run underneath a H.T. line it is carried by a stretched steel rope. The cable is hung to the rope at intervals of 2 or $2\frac{1}{2}$ feet by open hooks of galvanised iron strip attached to the cable by small collars or clips. After the steel rope has been strained up to the right degree the open hooks are slipped over it and the telephone cable is carefully drawn along by means of a rope. As a hook comes to a supporting point it is lifted off by hand and placed on the steel rope again beyond the obstruction. The cable must be carried by the rope all the time, even whilst being unwound from the drum. Sharp bends and excessive pulling must also be avoided if the thin lead covering is not to be damaged.

The exact tension to which a line must be set depends on the temperature

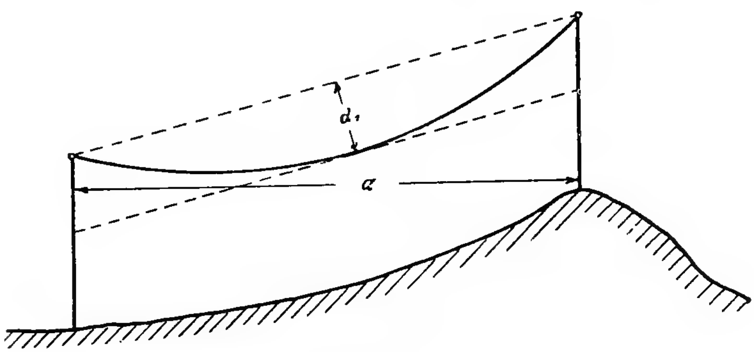


Fig. 214.

existing at the time. A good thermometer is, therefore, essential in line erection work. The bulb should be wrapped round with wire of the same material as that which is being erected, because it is found that, in sunshine, the wire temperature may differ appreciably from the temperature of the surrounding air.

As a check the sag of the line should be noted after the erection has been carried out with the dynamometer, because the latter is not infallible. One way of doing this is to mark off a distance equal to the correct sag downwards along each of the two masts, starting from the insulator, and then to note whether the lowest point of the wire falls in the line of vision joining the two marks. With the pocket level described on p. 213 this determination can be carried out from one mast. The instrument should preferably be fitted with a clip for fastening it on a level with the insulator top. After setting it up level the telescope is turned on to the corresponding insulator on the next mast. Now lowering the instrument by an amount equal to the correct sag, the line of sight of the telescope should include the lowest point of the wire if the tension is correct. This method is also applicable when the suspension points are at different levels. The distance

d_1 between the line joining the two supporting points and the parallel tangent to the curve of the wire is the correct sag for the span a (see Fig. 214). The same instrument can be used to determine the sag for the auxiliary spans a' and a'' dealt with in equations 4 and 5. The correct sag is set out downwards from one of the supporting points; the instrument is fixed at the point so found and the telescope is there set level. If the wire is correctly erected the line of sight will coincide with the horizontal tangent to the line (*i.e.*, will include the lowest point of the line or vertex of the parabola).

An entirely different method of checking the sag* consists in determining the natural time of swing of the line considered as a pendulum.

An overhead wire can easily be set swinging in a regular manner by taking hold of it near one of the supporting points and moving it to and fro laterally with the proper frequency. The natural frequency of such a pendulum is:

$$n = \frac{1}{\pi}\sqrt{\frac{g \times M \times h}{K}}$$

where

n = No. of single (half) swings per second;
g = acceleration due to gravity;
M = mass of the wire;
h = distance of the centre of gravity of the system from the axis of swing);
K = moment of inertia of the pendulum.

The moment of inertia of a parabola is

$$K = \frac{8}{15} M \times d^2,$$

where d is the distance of the vertex of the parabola from the axis of swing, *i.e.*, the sag; the distance of the centre of gravity from the axis of swing is $h = \frac{2}{3} d$.

Putting these values in the above expression and considering the number of (half-) swings per minute $= n_1 = 60\, n$:

$$n_1 = \frac{60}{\pi}\sqrt{\frac{5 \times g}{4d}}$$

$$\text{or } d = \left(\frac{420}{n_1}\right)^2 = \text{inches} \quad . \quad . \quad . \quad . \quad 70.$$

This formula holds for all materials and for all lengths of span, as neither the mass nor the length enter into it. It also holds for wires hanging between points at different levels. Table 38 gives the values of the frequency (in half-swings per minute) for the sags usually met with. The method is specially useful as a check on the sag both after and during erection. It is, however, only applicable with safety if the air is still and if the line has not more than two points of attachment. It is carried out as follows:—

* Dreisbach, E. T. Z., 1909, p. 1218.

A workman standing on one of the masts grasps the line loosely between finger and thumb about a foot away from the insulator and gradually sets it swinging by means of slight sideway pressure. It is an easy matter to get hold of the right frequency for these pressures by looking along the line and following its motion. The deflection sideways produced in the line should not be greater than is necessary to follow it easily by eye—in any case not more than 10° out of the vertical. As soon as the wire is swinging regularly the swings in one minute are counted (one left-hand swing and one right-hand swing being counted as two swings). From the number so found and the table the value of the sag can be determined at once. In the case of short spans with small sags it is more convenient to count the complete swings rather than the half-swings. Lines lying between supports at different levels should be set in motion from the lower support.

TABLE 38.—*Determination of the Sag of a Line from its Natural Frequency.*

Half-Swings per Minute.	Sag in Inches.	Half-Swings per Minute.	Sag in Inches.	Half-Swings per Minute.	Sag in Inches.	Half-Swings per Minute.	Sag in Inches.	Half-Swings per Minute.	Sag in Inches.	Half-Swings per Minute.	Sag in Inches.
30	196	43	95	56	56	78	28·7	104	16·1	130	10·3
$30\frac{1}{2}$	190	$43\frac{1}{2}$	93	$56\frac{1}{2}$	55	79	28·4	105	15·9	131	10·1
31	184	44	91	57	54	80	27·6	106	15·7	132	10
$31\frac{1}{2}$	178	$44\frac{1}{2}$	89	57·5	53	81	26·8	107	15·4	133	9·9
32	172	45	87	58	52	82	26	108	15	134	9·8
$32\frac{1}{2}$	167	$45\frac{1}{2}$	85	58·5	51·5	83	25·6	109	15	135	9·7
33	162	46	83	59	50·5	84	24·8	110	14·6	136	9·5
$33\frac{1}{2}$	157	$46\frac{1}{2}$	81	$59\frac{1}{2}$	50	85	24·5	111	14·2	137	9·4
34	152	47	79	60	49	86	23·6	112	14·2	138	9·1
$34\frac{1}{2}$	148	$47\frac{1}{2}$	78	61	47·5	87	23·2	113	13·8	139	9
35	144	48	76	62	46	88	22·8	114	13·4	140	8·9
$35\frac{1}{2}$	140	$48\frac{1}{2}$	75	63	44	89	22	115	13·1	141	8·7
36	136	49	73	64	43	90	21·7	116	12·9	142	8·6
$36\frac{1}{2}$	132	$49\frac{1}{2}$	71·5	65	42	91	21·2	117	12·8	143	8·5
37	128	50	70	66	40·5	92	20·8	118	12·6	144	8·4
$37\frac{1}{2}$	125	$50\frac{1}{2}$	69	67	39·5	93	20·5	119	12·5	145	8·2
38	122	51	67·5	68	38	94	20	120	12·2	146	8·1
$38\frac{1}{2}$	118	$51\frac{1}{2}$	66	69	37	95	19·7	121	12·2	147	8
39	116	52	65	70	36	96	19·3	122	11·8	148	7·9
$39\frac{1}{2}$	113	$52\frac{1}{2}$	64	71	35	97	19	123	11·7	149	7·8
40	110	53	63	72	34	98	18·5	124	11·4	150	7·7
$40\frac{1}{2}$	107	$53\frac{1}{2}$	61·5	73	33·2	99	18·1	125	11·3	152	7·5
41	105	54	60·5	74	32·5	100	17·7	126	11·1	154	7·4
$41\frac{1}{2}$	102	$54\frac{1}{2}$	59	75	31·2	101	17·3	127	10·9	156	7·1
42	100	55	58	76	30·5	102	17	128	10·7	158	7
$42\frac{1}{2}$	97	$55\frac{1}{2}$	57	77	29·5	103	16·5	129	10·5	160	6·7

The values of tension and sag should, preferably, be written out in tabular form for the use of the wiremen, as the employment of curves often leads to errors. The required values are given in Tables 9 to 12.

The lines are generally erected at a temperature at which the stress in them is very low ; it is therefore necessary to subject the wire, before adjustment, to a stress 15 or 20 per cent. above the maximum stress it will ever reach in order to smooth out slight kinks and bends. In any case these kinks would be removed the first time the wire was subjected to its full stress and this would subsequently cause trouble by unduly increasing the sag.

Stranded cables are not only preferable for overhead work because of their greater strength, but also because the erection work is simplified by their flexibility. It is therefore advisable to use stranded cables of hard drawn copper wire for sections above ·015 square inch and of medium copper wire for sections above ·04 square inch. The small additional cost is easily balanced by the reduced labour charges in erection.

19. RULES AND HINTS FOR THE DESIGN AND ERECTION OF OVERHEAD LINES.

THE importance of the duty fulfilled by the overhead line, viz., the transmission of power from the generating station to the far-distant consumer, makes it necessary to employ every care in planning it and in constructing it. A straight, unobstructed line, as free from angles and curves as possible, offers great advantages from the point of view of reliability, maintenance, and supervision. Care in these points generally also leads to the cheapest construction and the minimum charges for repairs. By skilful choice of the route the average span can often be appreciably increased without using taller or stronger masts, and in this way the number of masts required is reduced. The running of lines along roads is a common practice on the Continent, but one not to be encouraged, as it means that the line has to be constructed with a special degree of security, and this adds to the cost. Also the insulators in these situations are especially exposed to damage through stone-throwing. A good plan, where possible, is to run the line parallel to the road, but at a distance of 70 to 100 yards from it. This facilitates transport and makes supervision and repair easy.

The use of the longest possible spans is a decided advantage. Short spans of 40 to 45 yards are still often met with, but they lessen the reliability of the installation.

Every insulator is a possible source of trouble. and their number should, therefore, be kept as low as possible. High-tension schemes for 20,000 volts or more, especially, should be carried out on the long-span plan with spans up to 200 yards. A reduction in the number of supporting points is also a great aid to the running of a straight line, as it reduces the way-leave trouble. In many districts the question of way-leave forms one of the greatest obstacles in the scheme.

The first consideration in erecting a line should be reliability, whilst cost should take the second place. The degree of reliability demanded differs from case to case. Thus a branch line leading to a small village will not require to be carried out with the same security as the main line running through a number of towns or as the line for a factory in which the failure of the current means heavy loss and disorganisation. The object of the line must, therefore, be taken into account if a reasonable relation between cost and reliability is to be attained.

The simplest and cheapest form of line, suitable for small villages or private houses, is that erected on simple impregnated wooden poles with a span not exceeding 87 yards (rules of the V. D. E.) or on A poles with spans up to 175 yards. By introducing iron masts mounted in concrete at angles and crossing points, and, in any case, arranging that these strain masts occur at intervals of 1,200 to 1,500

yards at most, the security of the line will be sufficient for any installation up to 20,000 volts and of moderate size. Increased mechanical security is attained by the employment of iron masts throughout. The strength and size of such masts can be increased to almost any extent and arranged to meet almost any conditions.

Before surveying the route of a line the positions of the switching and transforming sub-stations must be determined. The former must be chosen both to suit the present installation and to be conveniently situated with regard to future extensions. The best points to choose are those at road crossings in the neighbourhood of villages.

The transforming sub-stations must be chosen to suit not only the long-distance transmission line, but also the low-tension distributing networks to be supplied from them. In this connection a difference of opinion may easily arise between the line engineer and the distribution engineer, and in coming to a decision the convenience for the high-tension line should be the determining factor. In general the sub-stations will be placed around the periphery of the inhabited district to be supplied, as the crossing of buildings by high-tension lines should be avoided except in quite special cases.

Roads, and postal lines running along them, can generally be crossed at any point, but in the case of railways thc crossing points have to be specially selected to meet the running conditions. It is advisable, therefore, to settle these points by consultation with the railway authorities at an early stage.

At the present time many authorities still insist on crossings being carried out at right angles, and, since the line seldom reaches the road or railway at right angles, a more or less pronounced bend is involved. The loading of the masts and insulators is deleteriously affected by this and the security diminished. Sometimes a slanting crossing is permitted, and probably in the future this will become the rule. In any case the advantages of the crossing taking place in the direction of the line should be pointed out when making the application.

The floor space necessary for the heavy foundations of the masts required at road and railway crossings is often a source of trouble. Permission to use the railway property or the property of the road authority is generally refused. Private owners must, therefore, be approached and their written leave obtained before further progress can be made with the planning of the route of the line. Large masts are objected to, and often leave is only obtained for their erection after the payment of a considerable sum.

Trees standing in the way of the line can be bridged over if they are not too tall. The distance from the line, in the case of fully-grown trees, should be made at least 3 yards. The taller trees must either be got round by diverting the line or must be bought up and cut down before commencing work. After the work has once been begun on the line the owners are liable to demand high prices for concessions. In some cases permission to remove trees is refused at any cost. Lines passing beside trees should be kept at least 5 yards away. If a wood is to be passed through a clearance of at least 10 yards in width should be made to avoid danger from falling trees or boughs.

When a power line runs parallel to a postal line it must be kept at a distance

of 10 yards or else must be constructed with increased security. In the case of railway lines the power line must lie at least 3 yards from the centre of the nearest rails, measured horizontally, or else the mast must be constructed with a factor of safety of at least 5 with regard to stability on its foundations (a very expensive form of foundation).

The inductive effect on the postal wires must be reduced to a minimum by transposition of wires. When lines run parallel to one another they must be separated sufficiently to prevent falling portions of one line endangering the other. If possible it is advisable to keep the two lines quite separate, despite the increased cost of supervision.

Not only should switching stations be provided, where the several portions of the line can be switched off under load by means of oil switches, but every branch line should be provided with a section switch by means of which it can be disconnected. These are a great convenience in repair work.

A difference of opinion still exists with regard to the installation of an earthing wire or wire rope along the tops of the poles. In America these have given excellent results. In one case a line, which had previously suffered heavily from lightning strokes, was completely protected by the running of such a wire. In Europe the use of the earthing wire has not been very widespread, but recently a change of opinion in favour of it has been noticeable. In the section on "Earthing" the advantages of such a continuous earth wire with regard to the earthing of the masts were pointed out.

When a line passes over high land and low land in turn the earth wire serves as a convenient means of equalising the differences of potential of the atmosphere at the different levels. Another advantage is the added mechanical strength which it gives to the supporting structures. If a breakage of the line wires occurs the resulting unbalanced pull is taken up by the earthing wire and the remaining lines and the masts are relieved of excessive stress. If the rope is made sufficiently strong the intermediate poles or mast can be of lighter construction, although this saving is mostly lost again because they have to be taller in order to carry the earth wire.

In rocky ground the continuous earth wire proves practically the only means of earthing the masts thoroughly.

20. INSTRUMENTS FOR SURVEYING AND LAYING-OUT THE ROUTE OF A LINE.

THE surveying and measuring work in connection with an overhead line is greatly simplified and expedited if the instruments employed are thoroughly understood and properly employed. A short description of the various instruments and the methods of using them will therefore not be out of place.

(1) *Measuring rods* are generally rectangular wooden rods, impregnated with linseed oil, 3 to 5 yards long and shod with metal. They are marked off with nail heads into 2 or 3 feet lengths, alternately black and white or red and white.

(2) *The steel measuring tape* is made in lengths of 20 to 30 yards, with a breadth of $\frac{3}{8}$ to $\frac{3}{4}$ inch and a thickness of $\frac{1}{64}$ to $\frac{1}{32}$ inch, and is fitted with loose rings at the ends for the marking pins. The latter are of wood about 1 inch in diameter and fitted with steel points. The marking on the tape is either engraved or is in the form of small brass plates riveted on and marking the 1 foot, 1 yard, etc., lengths more prominently.

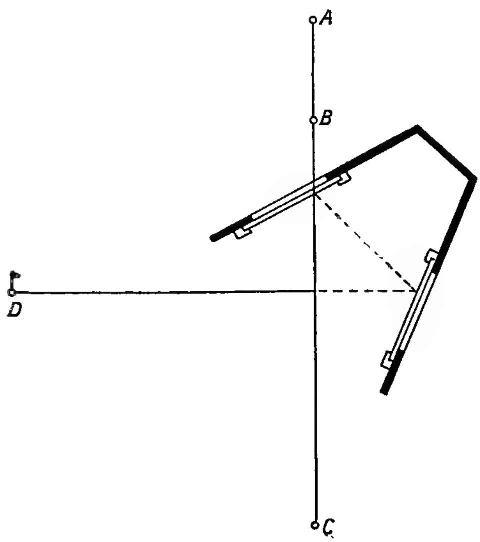


Fig. 215.

(3) *Ranging poles* are used to mark the sighting points. They are wooden rods (impregnated with oil) about 1 inch in diameter, 2 to 3 yards long, and fitted with a strong steel point at one end. On hard ground or plaster into which the point cannot be forced the rods are held in position by an iron tripod arrangement. They are painted alternately red and white or black and white in 2-foot lengths.

(4) *The levelling staff* is generally made in a length of from 3 to 5 yards of best dry wood, affected as little as possible by moisture and temperature. One side is accurately marked in feet and hundredths of a foot, and a hardened steel end is fitted. The marking is done with inverted figures so that they can be conveniently read in the telescope. In order to make it more portable the staff is generally made up in several sections which either slide together telescopically or are hinged together. The hinged type is preferable, as all the sections of the staff are then of one width whilst with the sliding type the upper sections are of reduced width, and this makes long-distance readings difficult. Often

small plummets are fitted at the back of the staff to simplify its vertical alignment.

(5) *Pedometers.*—For the purpose of making rapid approximate measurements distances are sometimes paced off. The mean length of pace of the average man is about 32 inches. Before employing this method the actual length of pace should be determined by repeated trial. Numerous instruments for counting the number of paces are in use. The most convenient are small pocket instruments, in the form of watches, called pedometers. These are carried in the waistcoat pocket as nearly vertical as possible. At every pace a lever rocks over and is drawn back again by a spring, and in this way a pawl and ratchet actuates the recording pointer.

(6) *The optical square* is used for marking out positions at right angles to one another (off-sets). It consists of two mirrors fixed in a box at 45° to one another and viewed through eye-pieces (Fig. 215). If a perpendicular is to be erected on *AB*, or its extension, the position of the pole or flag *D* must be adjusted

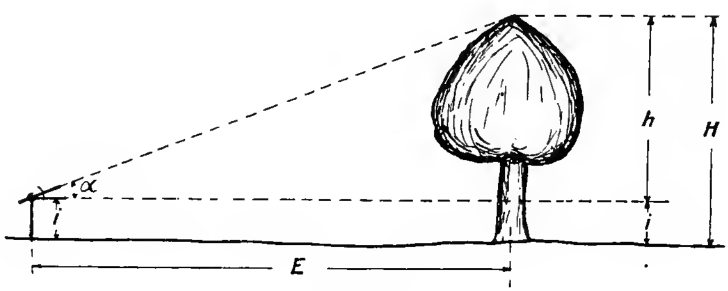


Fig. 216.

until the poles *AB* viewed over the mirror appear to coincide with the doubly reflected image received from *D*.

If a perpendicular from a fixed station *D* is to be dropped on to a chain line *AB* the observer moves along *AB* until the image of *D* coincides with the poles *AB*. The accuracy of the instrument would be indicated by the fact that the point at which the line from *D* falls on *AC*, is the same whether the measurement is made looking in the direction *AC* or in the direction *CA*.

(7) *The cross-shaft* consists of a small hollow cylinder with sight-slits inserted at such points that the various lines of sight cross at definite angles. The instrument is mounted on a staff stuck in the ground at the apex of the angle to be set out. By taking sights through the appropriate sight-slits the directions of the lines enclosing the desired angle are found.

(8) *Pocket telescopic level.*—In order to determine heights of masts, trees, etc., for insertion in cross-section plans the pocket level will be found a speedy and sufficiently accurate instrument. It consists of a telescope and level mounted on a divided circle on which the angle which the telescope makes with the horizontal can be read. It is not advisable to use the instrument in the hand, and a suitable carrier with a steel point for fixing in the earth is usually provided.

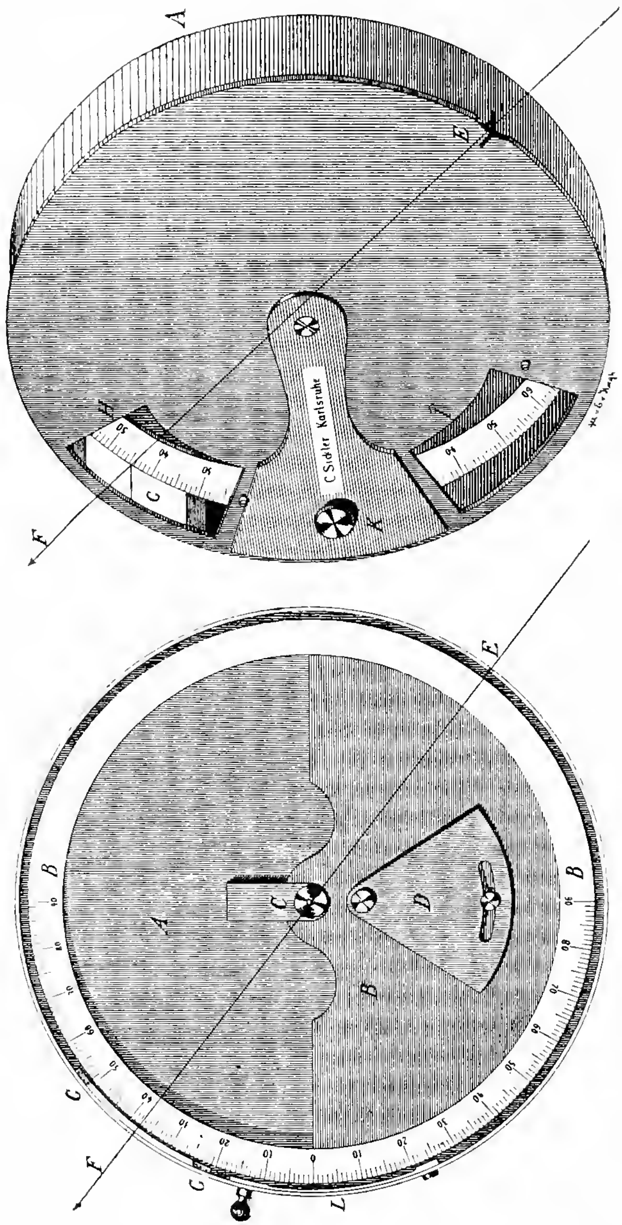


Fig. 217.

If h is the height to be measured and E the horizontal distance of the elevated point from the centre of the telescope (Fig. 216), then

$$\tan \alpha = \frac{h}{E} ; \; h = E \tan \alpha .$$

If i is the height of the telescope above the ground the total height of the distant object will be

$$H = i + h = i + E \tan \alpha.$$

(9) *The clinometer* (Fig. 217) is an instrument arranged for use in the hand for determining differences in level or the corresponding elevation angles. In one form it consists of a metal case A in which a graduated semi-circle B is arranged to swing freely and this sets itself horizontal under the action of the adjustable weight D. By turning the case the sight line EF is brought to bear on the distant object, and the angular elevation is then read off on the scale B by means of the line on the cover-glass G. The spring L serves to damp the swings of the scale. The difference in level h (Fig. 218) is found from the expression

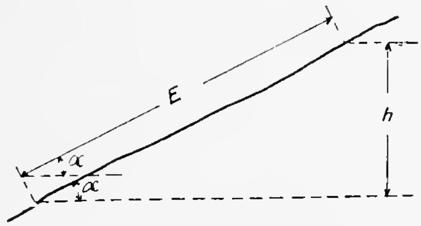


Fig. 218.

$$h = E \sin \alpha.$$

(10) *The theodolite* (Fig. 219) is used to measure both horizontal and vertical angles. By means of a vertical divided circle heights or elevations can be determined, whilst the telescope, with its spirit level, serves for measurements in the horizontal plane.

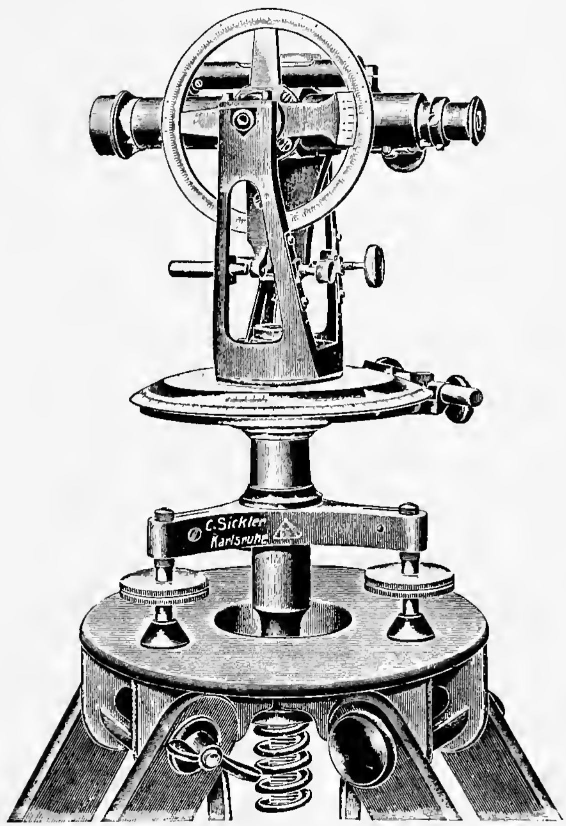


Fig. 219.

If the theodolite is fitted with a compass and if the telescope is arranged for measurements of distance it is called a tacheometer. The theodolite is mounted on a parallel plate arranged for attachment to a tripod stand. The various parts of the instrument (Fig. 220) are:

(a) The levelling plate and screws D.

(b) The divided circle L, which in the simpler theodolites is attached rigidly to D, but in the repetition form of instrument can be rotated on the under-frame. The scale is divided into whole degrees and halves or thirds of degrees. In the

older instruments the 360° division is still found, but the newer ones employ a 400° division.

(*c*) The alidade *AA* is a circular disc attached to the conical axis *C* and arranged to turn concentrically within the divided circle *L*. At diametrically opposite points on the alidade verniers or micrometer microscopes are carried. By means of clamps and micrometer screws the alidade can be fixed in relation to the divided circle. The alidade carries two *A* frames which support :—

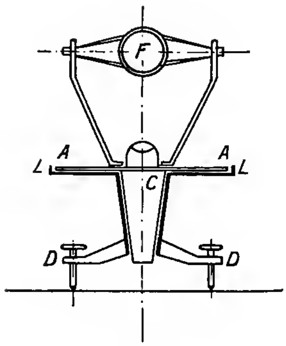


Fig. 220.

(*d*) The telescope *F*. This is carried either concentrically or eccentrically, according to whether the turning plane of the collimation axis (or visual axis : the line joining the optical centre of the object with the cross lines) passes through the vertical axis *C* or not. The bearings are rigidly fixed to the alidade and are either of the closed or open type, according to the method adopted for reversing the telescope.

In the tacheometer two additional webs equidistant from the horizontal cross web are arranged in the diaphragm plane.

(*e*) The levels for fixing the horizontal axis of the telescope and for setting the whole instrument horizontal. For these purposes either circular spirit-levels or, better, two tubular spirit-levels set at right angles to one another are employed.

For the purpose of measuring angles of elevation a vertical divided circle is fixed on the telescope axis, and parallel to it a delicate spirit-level is fixed. The alidade is provided with a fine adjustment.

(11) *The miner's dial* (*telescopic compass*) is often the only instrument available for setting-out in obstructed country. In one form it consists of a flat round case with a glass cover and carrying a magnetic needle pivoted over a divided circle. Parallel to the N. and S. marking on the latter a telescope is fixed. A circular spirit-level and a tripod are provided for setting the instrument horizontal. When an object is viewed through the telescope the needle position indicates the angle by which the line of sight deviates from the magnetic meridian. In comparing directions read off a map with directions actually observed with this instrument allowance must be made for the difference between the magnetic meridian and the true astronomical meridian, which, for Mid-Europe, is about 10°.

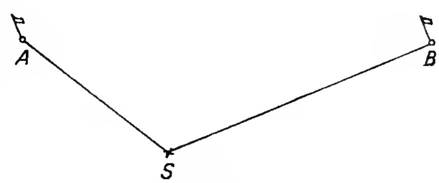


Fig. 221.

The Simple Measurement of Angles.

In order to measure such an angle as *ASB* in Fig. 221 the theodolite is set up vertically over *S* and its axis is set truly vertical by means of the levels, the result being checked with the instrument in two distinct positions at right angles to

one another. The telescope is then turned to the point A (at which, as well as at point B, poles will have been set up) and the vernier is brought to the 0° point on the divided circle. By turning the alidade now until the telescope points to B the angle required can be read direct on the divided circle.

For exact measurements the telescope is inverted and a second set of readings taken. The mean of the two results is then the exact value.

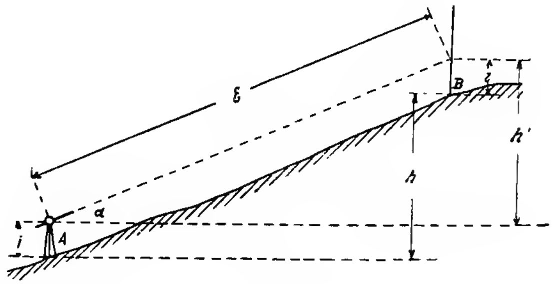


Fig. 222.

The measurement of a vertical angle α is carried out in the same way, but using the vertical divided circle and the spirit-level fixed parallel with it.

Trigonometrical Determination of Heights at Small Distances (Fig. 222).

The theodolite is set up vertically at the point A, the telescope is directed to the distant point B (marked by a levelling staff), and the angle α is then deter-

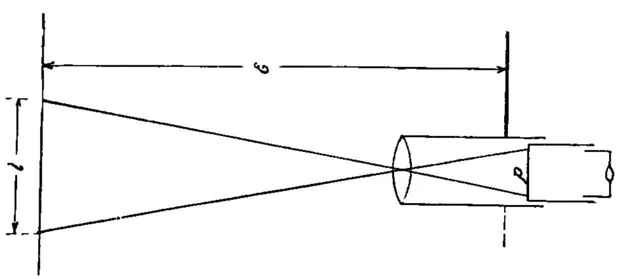


Fig. 223.

mined by the vertical divided circle. If the point visualised on the levelling staff has been chosen at the same height above B as the height i of the telescope tipping axis above the point A, then

$$h = h' + i - i, \text{ where } h' = E \sin \alpha$$

or

$$h = E \sin \alpha$$

Measuring Distances with the Theodolite.

The method of measuring distances by means of the tacheometer theodolite is based on the principle of arranging the unknown distance as the height of a triangle (generally isosceles and very pointed) and determining its length from the known angle at the apex and the known base. At one end of the distance E (Fig. 223) the instrument with its telescope is set up and directed horizontally to a staff set up at the other end. The length l on the staff bounded by the two spaced cross webs in the telescope is then observed. The required distance E, the base length l, and spacing of the cross webs p are definitely related to one another

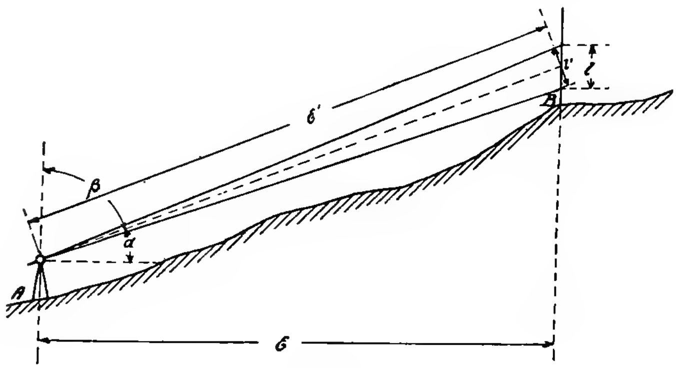


Fig. 224.

in a manner depending on the type of telescope used. For a telescope with a Ramsden eye-piece the relation is :—

$$E = c + kl$$

where c is the distance between the front objective and the vertical axis and

$$k = \frac{F}{p} = \frac{\text{Focal length of objective.}}{\text{Spacing of cross webs.}}$$

k is generally made a round number such as 100.

Measuring Distances with an Inclined Line of Sight (Fig. 224).

The length l observed between the cross webs is, with sufficient accuracy,

$$l = \frac{l'}{\cos \alpha}$$

The distance

$$E = E' \cos \alpha = E' \sin \beta$$

and $$E' = C + kl'$$

therefore

$$E = C \cos \alpha + kl \cos^2 \alpha$$

or $$E = C \sin \beta + kl \sin^2 \beta.$$

21. SURVEYING THE ROUTE OF A TRANSMISSION LINE.

THE direction to be followed by the main line is generally determined by the selection of the points for the generating stations, whilst the directions of the branch lines are fixed by the transformer or sub-stations. The road and rail crossing points are consequently known and can be handled in accordance with the rules in the previous section.

The maximum span between the masts is determined by the height and strength of the selected construction and by the question of economy.

From the point of view of electrical safety the fewer the supporting points the better. Economy would point to the same rule, so that it is advisable to use the maximum span as often as possible.

A constant distance between supporting points cannot, of course, be maintained throughout, because the masts cannot be erected at will in any position.

The ground owners will generally only give permission on condition that the mast is placed in the boundary between fields where it will interfere least with the working of the land.

The determination of the ownership of the various pieces of land is best effected in consultation with the local authorities. The parish or town maps and their indexes are also useful, but are not always quite up to date on questions of ownership.

In order to avoid mistakes it is advisable to interview the owners on the spot, when the direction of the line, size of the mast feet, etc., can be more fully explained.

The fixed points must be indicated by stakes, which should be driven 2 or 3 feet into the ground, for safety, and should carry a clearly visible number.

Strain towers, angle masts, and the more important points in the line generally should have their positions fixed by reference to boundary stones, trees, or, failing these, to several stakes, so that in case one of these stakes is removed accidentally the position of the mast will still be sufficiently indicated. The measurements so made should then be entered on the plan (Plate I.).

Special care should be taken with regard to private or public boundary lines. Omissions in this respect may lead to endless trouble.

The plan of the line is drawn in on any convenient map available for the district, the scales of such maps varying from 1 : 100,000 to 1 : 2,500.

SURVEYING IN OPEN COUNTRY.

Small sections are determined by direct measurements between ranging poles, which remain standing until the fixed points are marked by stakes driven in.

For distances over half a mile it is more advantageous to work with the theodolite. The instrument is set up in the centre of the section if this is longer than about two miles. As a start the instrument is moved at right angles to the line direction until a point is reached where, on reversing the telescope, both ends of the section are brought into the visual line. The setting up of the ranging poles can then be commenced in both directions.

Surveying in Obstructed Country.

The survey work is more difficult when it is impossible to see both end points of the section from any one point within the line of route.

When the differences of level are small tall signal masts can be used to make the end points visible, or small gas balloons anchored by three strings can be used for the same purpose. If these aids are not practicable an attempt should be made to find a point to one side of the line from which both ends are visible.

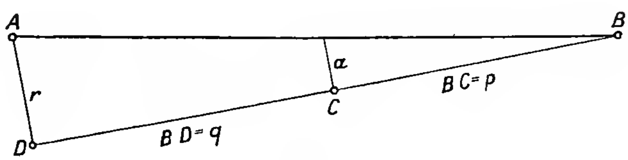


Fig. 225.

In Fig. 225 the end B of the line is not visible from the other end A. The intermediate section can, however, be dealt with by choosing a point C, to one side, from which both A and B are visible. The telescope at C is first focussed on B, and it is then inverted and a point D, near to A and lying in the line BC produced, is marked. The distance $AD = r$ can be directly measured and the distances CB and CD can be determined by means of the double cross webs of the theodolite. The length a, through which the instrument has to be moved to reach the line, is found from the proportion

$$r : a = q : p$$

$$\text{or} \qquad a = \frac{r \cdot p}{q}.$$

A similar procedure can be used when, although the one end is invisible from the other, the general direction of the line is known by reference to a map. With the theodolite the approximate line BD is marked out. D will, in general, not coincide with the correct end point A, but, since $AD = r$ can be directly measured and the lengths $CB = p$ and $DB = q$ are already known, the distance a by which any point such as C must be moved to reach the true line can be at once calculated from the expressions

$$a = \frac{r \cdot p}{q}.$$

TABLE 39.—SCHEDULE OF MATERIAL FOR TRANSMISSION LINE...........

High-Tension Supply: .... volts.
Telephone ....

Copper Conductor .... Square inch cross-section .... Strands of .... diameter wire.
Bronze „ .... „ „ .... „ .... „ „

Supporting Point.		Ground Landlord.		Distance between Masts.	Wooden Poles.						Iron Masts.					Earthing.				Cross-Arms.		Insulator Pins.		Insulators.		Mast Switch. Drawing No.	Safety Bows. Drawing No.	Earthing Bows. Drawing No.	Safety Clips. Drawing No.	Safety Nets.				Earth Wire.	
Series No.	Line No.	Name.	Address.		Type Drawing No.	Height above Ground.	Foundation.	Depth of Hole.	Strengthened by Stay	Strut Material.	Type Drawing No.	Pull at the Top.	Foundation.	Foundation to Drawing No.	Concrete Mixture.	Earth Plate Material. Size.	Pipe with Collars. Length, Diameter.	Earth Wire Material, Cross-Section.	Lead Discs, Screws, Terminals.	For H.T. Line. Drawing No.	For Telephone Line. Drawing No.	H.T. Line. Drawing No.	Telephone Line. Drawing No.	Type No.	Type No.					Longitudinal Wires. Diameter.	Cross Wires. Diameter.	Cross-Arms Drawing No.	Stretching Screws. Inches	Material Area.	Attachment. Drawing No.

Sundries:

Soft Copper Binding Wire .... square inch .... lbs.
Medium Copper „ „ .... „ .... „
Copper-clad Steel „ „ .... „ .... „
Solder .... „
Rosin .... „
Benzine .... „
Tar.. „

Tools:

Tool Case. No.................
Pulley Blocks..................
Pulleys.........................
Dynamometer for .... lbs. pull.
Rope ....
Ladders ....
Climbing Irons ....
Safety Belts ....

Carrriage and Erection of Masts and Foundation Work by
in accordance with Specification of ....
Erection of Line by Messrs. .... in accordance with
Painting by Messrs. .... in accordance with Agreeme
Commencement of Work on Masts ....
„ „ „ „ the Line ....
Supply started ....

Copper Conductor .... Square inch cross-section .... Strands of .... diameter wire.
Bronze ,, ... ,, ,, ... ,, ... ,, ,,

	Earthing.				Cross-Arms.		Insulator Pins.		Insulators.						Safety Nets.				Earth Wire.						
...tion ...ncrete ...ixture.	Earth Plate Material. Size.	Pipe with Collars. Length, Diameter.	Earth Wire Material, Cross-Section.	Lead Discs, Screws, Terminals.	For H.T. Line. Drawing No.	For Telephone Line. Drawing No.	H.T. Line. Drawing No.	Telephone Line. Drawing No.	Type No.	Type No.	Mast Switch. Drawing No.	Safety Bows. Drawing No.	Earthing Bows. Drawing No.	Safety Clips. Drawing No.	Longitudinal Wires. Diameter.	Cross Wires. Diameter.	Cross-Arms Drawing No.	Stretching Screws. Inches	Material Area.	Attachment. Drawing No.	Riveted Junction. Type.	Conical Junction. Type.	Conical End Connectors. Type.	Branch Line Terminals. Type.	Remarks.
																									To be Delivered at Railway Station.

Tools:

Tool Case. No.................
Pulley Blocks.................
Pulleys........................
Dynamometer for .... lbs. pull.
Rope ....
Ladders ....
Climbing Irons ....
Safety Belts ....

Carrriage and Erection of Masts and Foundation Work by Messrs..........
in accordance with Specification of ....
Erection of Line by Messrs. .... in accordance with Specification of ..
Painting by Messrs. .... in accordance with Agreement of ....
Commencement of Work on Masts ....
,, ,, ,, ,, the Line..
Supply started ....

[To face p. 221.

HIGH-TENSION SECTION :—

PLATE I.

High-Tension Line.

No. of Wires....area of each....diameter.
Material ......k_z = ...lbs. per square inch.
Maximum Stress ....lbs. per square inch.
Wind Pressure per foot run ....lbs.

Telephone Line.

No. of Wires....area ....diameter.
Material ......k_z = ...lbs. per square inch.
Maximum Stress ....lbs. per square inch.
Wind Pressure per foot run ....lbs.

Section inspected on ....
,, begun on ....
,, finished on ....
Sent in for checking on............
Building permission obtained on....
Material delivered on ....

Handed over to Contractor on ....
Mast erection completed on ....
Running of line begun on..........
,, ,, finished on........
Put in operation on ....

Contractor for Masts ....
,, ,, Line ....
Chief Engineer ....
Assistant Engineer..........

1	Column No		
2	Mast No.		
3	Profile of Line		
4	Plan of Line		
5	Distance	Ft.	
6	Sag	In.	
7	Difference in level	Ft.	
8	Distance from ground	Ft.	
9	Angle of line tension	°	
10	Max. pull on mast	lbs	
11	Type of mast		
12	Height above ground	Ft.	
13	Total height	Ft.	
14	Foundation Dimension		
15	Date		
16	Ground Landlord		
17	Remarks		

[*To face p.* 221.

In the case of long lines this method is somewhat difficult and clumsy, and it is better to proceed as follows :—

(1) Set up the theodolite at A (Fig. 226) and mark a point C' quite close to the line. Measure the angle $BAC' = \alpha$ as accurately as possible and determine the distance $CC' = a$ from a measurement of d by means of the double cross webs :

$$a = d \sin \alpha.$$

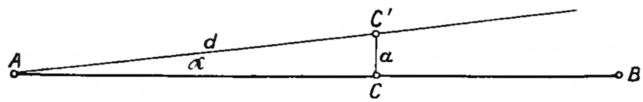


Fig. 226.

(2) Move the theodolite to C' and with it measure the angle $AC'B = 180° - \gamma$ (Fig. 227). The area of the triangle $AC'B$ is

$$\tfrac{1}{2}\, a \,.\, AB = \tfrac{1}{2}\, dd' \sin (180 - \gamma).$$

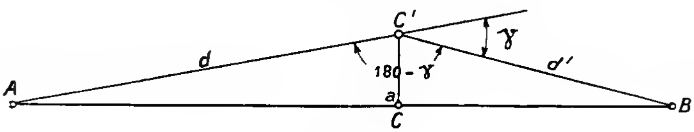


Fig. 227.

The distance AB can, with sufficient accuracy, be taken as equal to $d + d'$, so that

$$\tfrac{1}{2}\, a(d + d') = \tfrac{1}{2}\, dd' \sin \gamma$$

from which

$$a = \frac{dd'}{d + d'} \sin \gamma.$$

Recording the Results.

The observations made in the field for each section of the line are entered on a form such as that shown in Plate I., and this then serves as the basis of all future work. This form must contain full particulars as to the position of the several supporting points, type, size, and arrangement of the masts and foundations, road and railway crossings, angle points, differences in ground level, and details of the whole overhead gear. From it the necessary quantities can then be estimated and provided for by the order and stores departments.

The careful collection and distribution of all the necessary material is essential if an uninterrupted and economical progress of the line erection is to be ensured. All material should be marked with the reference number of the mast to which it belongs. The list of materials (Table 39, Plate II.) is a constituent part of the route map, and copies of it should be given not only to the engineers in charge,

but also to the workmen, so that no doubt shall exist as to the correct use of the material delivered.

At the same time as the list of quantities is issued by the technical staff to the ordering department full forwarding instructions must also be given, so that each store receives its correct supply and that the unloading of the heavy iron masts may be carried out under the most favourable conditions.

Supports Erected on Private Property.

As soon as the general route of the line has been determined and surveyed the names of the owners of the various pieces of ground on which supports are to be erected should be discovered and entered up. As the exact position of the masts is not yet known, and as some of the owners may refuse wayleaves, owners of property to the right and left of the desired route should also be noted.

When a mast is to be erected on a boundary line permission from the owners on both sides has to be obtained. The names are entered in a special list together with particulars as to the kind of mast to be erected in each case, and this is put in charge of some member of the staff specially qualified as regards tact, knowledge of the district, and of the local dialect for negotiating with the owners. All permits must be obtained in writing. For every mast, stay or strut, roof standard or bracket, a signed form giving full particulars of the arrangement should be prepared. A great deal of trouble, time and money, not to speak of legal proceedings, will be obviated if this rule is strictly adhered to. No mast should be erected or other work commenced until the whole of the permits and forms for the section are in the hands of the engineer in charge.

The crossing of land or houses by wires without the owners' permission is, in spite of opinions to the contrary, illegal.*

The signed form is the written agreement of the owner, for a certain consideration, to allow a definite portion of a transmission installation to exist on his land.

* The state of the English law on the subject of wayleaves, etc., has been summarised as follows by Mr. B. Welbourn in a paper read before the Institution of Electrical Engineers in January, 1914 :—

"(1) The Postmaster-General possesses powers for erecting telegraph and telephone lines (under section 2 of the Telegraph Act, 1892, and section 4 of the Telegraph Act, 1908), but the procedure to be followed is so cumbersome as to be almost useless. Even these powers are denied to electric supply authorities.

"(2) Under the Electric Lighting Acts the consent of the local authority must be obtained by a statutory undertaker previous to the erection of overhead wires, whether these are in the public street or on private land.

"(3) Non-statutory undertakers (such as iron and steel manufacturers, collieries, etc.) can dispense with the consent of the local authority, and both erect wires on private land and cross public roads, so long as the wires cause no obstruction above the roadway.

"(4) Non-statutory undertakers may erect overhead lines without compliance with the Board of Trade regulations, but the Board has power, if it thinks fit, to order such compliance."

The German law on the subject states :—

"The right of the ground owner extends also into the space above the ground surface and into the body of the earth under the surface. The owner, however, cannot interfere with work carried out at such a height that it cannot affect his interests."

(An owner's interests are affected if the possibility of risk to life or property through overhead lines is present.)

The permission can only be withdrawn under certain conditions which must be clearly stated in the form.

The form of agreement should be worded somewhat as follows :—

I AGREE that or their successors, as constructors of ,

(a) may attach a line support and the necessary stays, etc., to my house ;

(b) may erect a mast with its necessary supports, etc., on my land ;

(c) may run a transmission line over my land

I FURTHER AGREE that shall have access at all times to the buildings, grounds and annexes, and shall be free to carry out any work or alterations necessary for the proper maintenance of the supply. I undertake not to require the removal of the installation unless permanent damage to my buildings or property is being done and cannot be prevented, or unless, owing to structural alterations, the removal or modification of the installation becomes essential.

The , on the other hand, agrees to maintain the installation in good working condition and to compensate me for damage caused by any part of it.

This Agreement supersedes all verbal agreements.

Dated .

Permission to make use of the ground is seldom given without payment. A small charge only is generally made, varying between 3*s*. and 10*s*. for an ordinary wooden pole. For masts occupying a considerable floor space the charges are, of course, a good deal greater and in some cases the ground has even to be bought outright.

The question of the payment of an annual rent should not be entertained, as the owner thereby acquires the right of giving notice, and this may easily lead to future trouble. A form of payment advantageous to the electric supply company is the free installation of one or more lamps, but this should not include free supply of current, as a permanent charge is thus imposed on the station, and also a free supply of current generally leads to waste.

The erection of masts and wires should, as far as possible, take place after harvest time. Even so it is difficult to avoid some damage to the property during erection, and some arrangement should therefore be come to at the commencement in regard to the estimation of such damage. A useful plan is to form, with the aid of the local mayor, a commission of three in each district. Each owner should agree to this arrangement by signing some such form as the following :—

I AGREE that all damage caused by—

(a) the erection of the supporting masts for the line ;

(b) the erection of the line ;

(c) the cutting or clipping of trees

shall be paid for in accordance with the decision of the assessment commission of three members, and this decision shall be final and binding on me to the exclusion of all legal proceedings.

Payment is to take place within eight days of the commission's decision being arrived at.

Dated .

(Signed) .

Supports erected on Public Property.

Permission to use public property in the form of roads, lands, and buildings is easily obtained in cases where an agreement for the supply of electrical energy to the community has been come to. When this is not the case the local authorities have the right, just like private owners, to refuse permission for the erection of masts on their property or the carrying of wires over it. A draft agreement suitable for such a case is given below :—

Agreement.

The Local Authority of   and the   Electrical Company have this day come to the following agreement:

§ 1.

The Authority grants to the Electrical Company the free use above and below ground of the roads, places and common lands within their boundaries, for the erection of masts, etc., for an electric supply scheme and for transmitting electrical power over and through the district, provided that all the police regulations and bye-laws are complied with.

§ 2.

The erection of the line is to be carried out in conjunction with the Authority. A plan of the proposed line, to a sufficiently large scale, is to be deposited with the Authority before any work is commenced. For lines laid underground cross and longitudinal sections as well as the plan are to be submitted. The proposed positions of the masts are in the first place to be marked with pegs in the ground, and only after inspection and the carrying out of any necessary alterations in position is the work of erection to be proceeded with.

§ 3.

No obstruction of thoroughfares or prevention of free access to property must occur during the erection.

§ 4.

The Electrical Company is to carry out all its work in accordance with the Board of Trade Regulations (or Regulations of the Verband Deutscher Elektrotechniker) and to maintain it in good condition. The Authority retains the right to have the work inspected and tested by an expert.

§ 5.

The Electrical Company is responsible for all damage done during the erection or alteration work, and will satisfy all claims whether made by the Authority or by third persons.

After carrying out any work the Electrical Company must make good all roadways, etc., and leave them in their original condition or in the altered condition demanded by the Local Authority. The Electrical Company is to bear all the costs of such making good.

§ 6.

The Authority grants the permission stated in § 1 for the term of   years beginning on   19   . The Electrical Company is to carry out such alterations to its lines as may from time to time be required in the public interest or as are necessitated by other underground work or building operations.

§ 7.

The Electrical Company, without a permit from the Authority, may not sell or deliver electrical energy within the district, even if no public property is passed over by the service wires.

§ 8.

Two copies of this agreement are to be signed by both parties to it, and each party is to retain one of the copies.

Date .

(Signed) .

Date .

(Signed) .

The use of public roads and railway property is generally only permitted if a withdrawal clause is inserted in the agreement. Alterations or removals of line are, however, only demanded when they are unavoidable in the public interest (diversion or widening of roadway or railway), or if the undertakers have not complied with the terms of the agreement.

The legal position with regard to the State telegraph and telephone service is, in Germany, laid down in the Telegraph Bill of December 18th, 1899. This states that public telegraph lines may be erected on all public roads, places, waterways, etc., but that they must be so carried out as not to interfere with existing electrical installations. Any protective arrangements which may be necessary for the working of the telegraph line must be carried out at the expense of the postal authorities. If, on the other hand, a power scheme has to cross an existing postal line the cost of any protective arrangements must be borne by the power company.

Section 6 of the Bill obliges the builders of any power line to use every possible care to avoid interference with any existing telegraph lines.

In accordance with section 6, sub-section 2, the postal authorities must comply with any offer to divert or alter a telegraph line if without such alteration the carrying out of a transmission scheme required in the public interest would become impossible or decidedly more difficult.

The charges for such alterations fall on the postal authorities, provided that the owners or principal shareholders in the power scheme are the local public authority.

In England very wide powers have been conferred on the Post Office by section 2 of the Telegraph Act of 1892 and by section 4 of the Telegraph Act of 1908, which often give its requirements undue weight when in conflict with electric supply companies.*

* See paper by Mr. C. Vernier, "Journal of the Institution of Electrical Engineers," No. 223, Vol. 52, 1913, p. 17. See also p. 222, above.

22. THE MOST ECONOMICAL LENGTH OF SPAN.

It has already been pointed out repeatedly that the use of long spans adds to the security of the installation because the number of insulators and, therefore, of possible faults is reduced. The distance between masts cannot, however, be determined from this consideration alone, because the cost of installation also varies with the length of span. The minimum total cost is obtained with a certain length of span which may be called the "economical span." This is that span which makes the saving due to reduced number of supporting points just balance the increased charges for the taller and stronger masts necessitated.

The sag of a line does not increase linearly with the length of span but as the square of the latter, so that the required height of masts and the load on these increase rapidly for the longer spans.

The economical span is not of the same length for all lines. In level country it depends chiefly on the number, the cross-section, and the material of the lines. For given lines it is dependent in the first place on the kind of supporting structures chosen, in the second place on the way in which they are carried out. In hilly, undulating country much longer spans may be possible than on level ground by making use of suitable hillocks to mount the masts on and to give the necessary clearance.

A knowledge of the economical span does not necessarily mean that it should be used. If the cost of installation only increases slowly with increasing length of span beyond the economical one, it may pay to use a longer span in order to obtain the advantages which are bound up with a reduced number of supporting points. In the first of the following examples it will be seen that the economical span works out at 140 metres (460 feet), but since the cost has only increased by £5 when a 160-metre span is used the latter would certainly be preferable.

The example fully detailed in Table 40 and Fig. 228 and the further examples whose results are shown in the curves of Figs. 229—232 are only intended to emphasise this point. The actual cost figures used are only approximate. They vary with the changing state of the market and also from place to place, so that no generally applicable figures could be given. In these examples 75 per cent. of the masts are assumed to be mere supporting masts, 15 per cent. strain masts, and 10 per cent. corner or angle masts.

Fig. 229 refers to a 20,000-volt three-phase line 10 kilometres long with three copper wires each of ·055 square inch section ;

Fig. 230 to a 20,000-volt three-phase line 10 kilometres long with three copper wires each of ·078 square inch section ;

Fig. 231 to a 20,000-volt three-phase line 10 kilometres long with three copper wires each of ·108 square inch section, with a steel earthing wire ·044

square inch in section and a telephone cable supported by a steel wire rope ·062 square inch in section ; and

Fig. 232 to the same case as Fig. 231, except that there are two sets of three-phase lines (six wires each ·108 square inch in section) instead of one set.

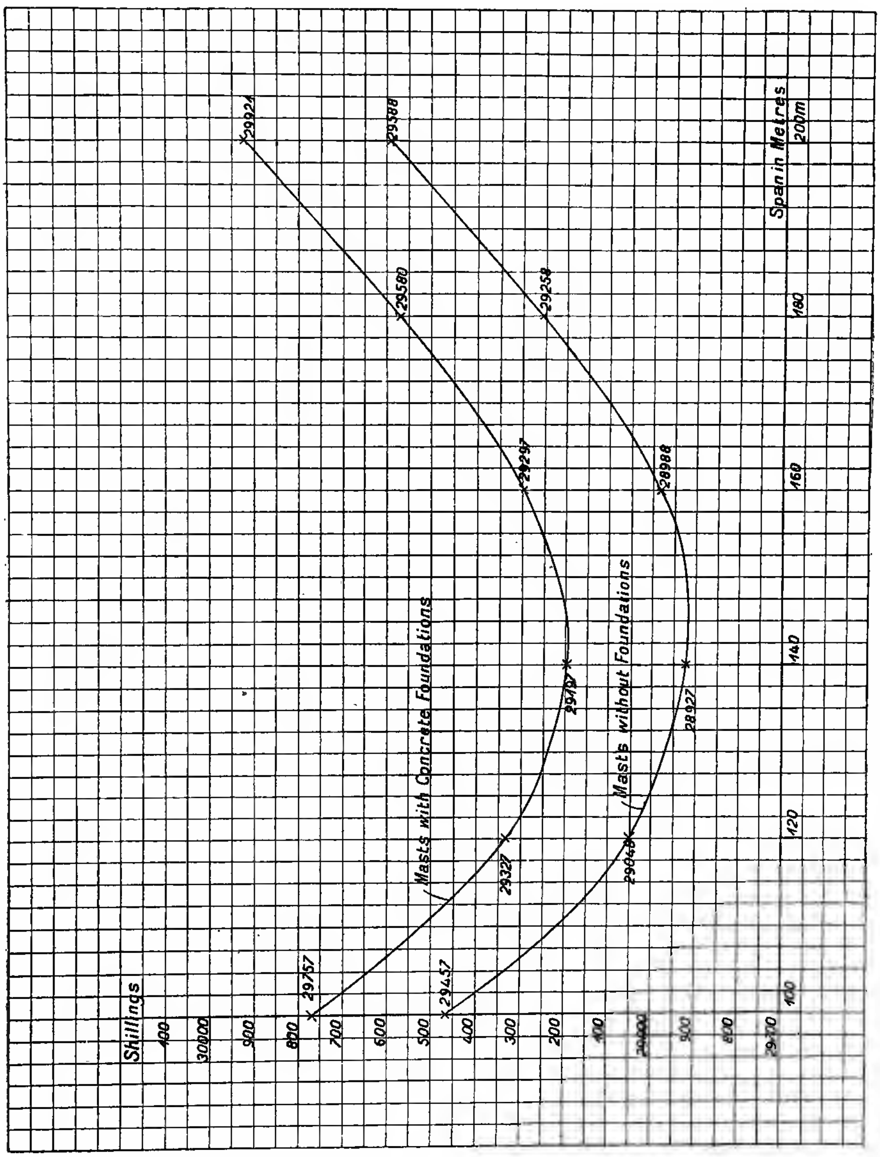


Fig. 228.

TABLE 40.—*Summary of the first cost of a H.T.* (20,000-*volt*) *three-phase line* 10 *kilometres* (6¼ *miles*) *long and consisting of* 3 × ·039 *square inch copper wires. Factor of safety* 2·5 *for supporting and corner masts and* 4 *for strain masts.* (*For Curve see* Fig. 228.)

Type of Mast.	Pull on Mast (lbs.).	Cost in Shillings of:									
		Mast with Cross-arms Insulators, etc.	Foundations and Earth Excavation.	Carriage, Erection, and Making Good.	Painting.	Total per Mast.	No. of Masts.	Total Cost of Masts for the 10 Km.	Copper Wire.	Erection of Wire and Earthing.	Total for the 10 Km.
1. Span = 100 metres (326 feet) requiring 100 masts 9 metres high.											
Supporting	375	59	19	13	6·5	97·5	75	14,727·5	12,150	2,880	29,757·5
Corner .	1,380	109	44	21	11	185	10				
Strain .	2,650	214	103	39	15	371	15				
2. Span = 120 metres (395 feet) requiring 84 masts 10 metres high.											
Supporting	450	69	22	15	7	113	62	14,357·5	12,150	2,820	29,327·5
Corner .	1,380	125	53	24	12·5	214·5	9				
Strain .	2,650	242	115	43	17	417	13				
3. Span = 140 metres (460 feet) requiring 72 masts 11 metres high.											
Supporting	530	82	26	17	8·5	133·5	54	14,287	12,150	2,760	29,197
Corner .	1,380	150	57	27	15	249	7				
Strain .	2,650	290	126	49	20	485	11				
4. Span = 160 metres (525 feet) requiring 63 masts 12·2 metres high.											
Supporting	600	97	32	21	10	160	47	14,447	12,150	2,700	29,297
Corner .	1,380	165	63	30	16·5	274·5	6				
Strain .	2,650	335	137	53	23	548	10				
5. Span = 180 metres (590 feet) requiring 56 masts 13·5 metres high.											
Supporting	670	120	36	26	12	194	42	14,790	12,150	2,640	29,580
Corner .	1,380	190	65	33	19	307	6				
Strain .	2,650	370	148	57	25	600	8				
6. Span = 200 metres (652 feet) requiring 50 masts 15 metres high.											
Supporting	760	135	41·5	30	13·5	220	37	15,191·5	12,150	2,580	29,921·5
Corner .	1,380	235	70	37	23·5	365·5	5				
Strain .	2,650	405	160	61	27	653	8				

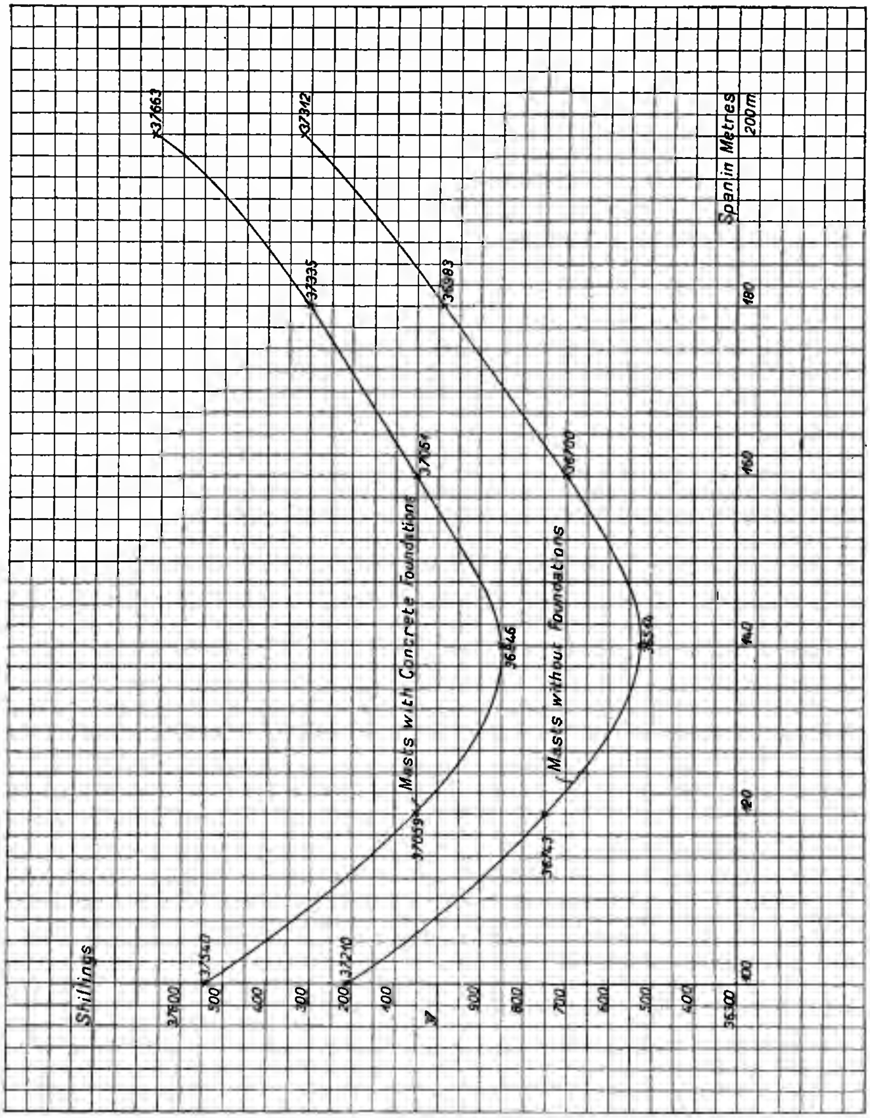

Shillings
Span in Metres
Masts with Concrete Foundations
Masts without Foundations
37663
37312
37335
36983
37151
36700
36846
37059
36743
37540
37210
100
120
140
160
180
200m
37400
300
200
100
900
800
700
600
500
400
36300

Fig. 229.

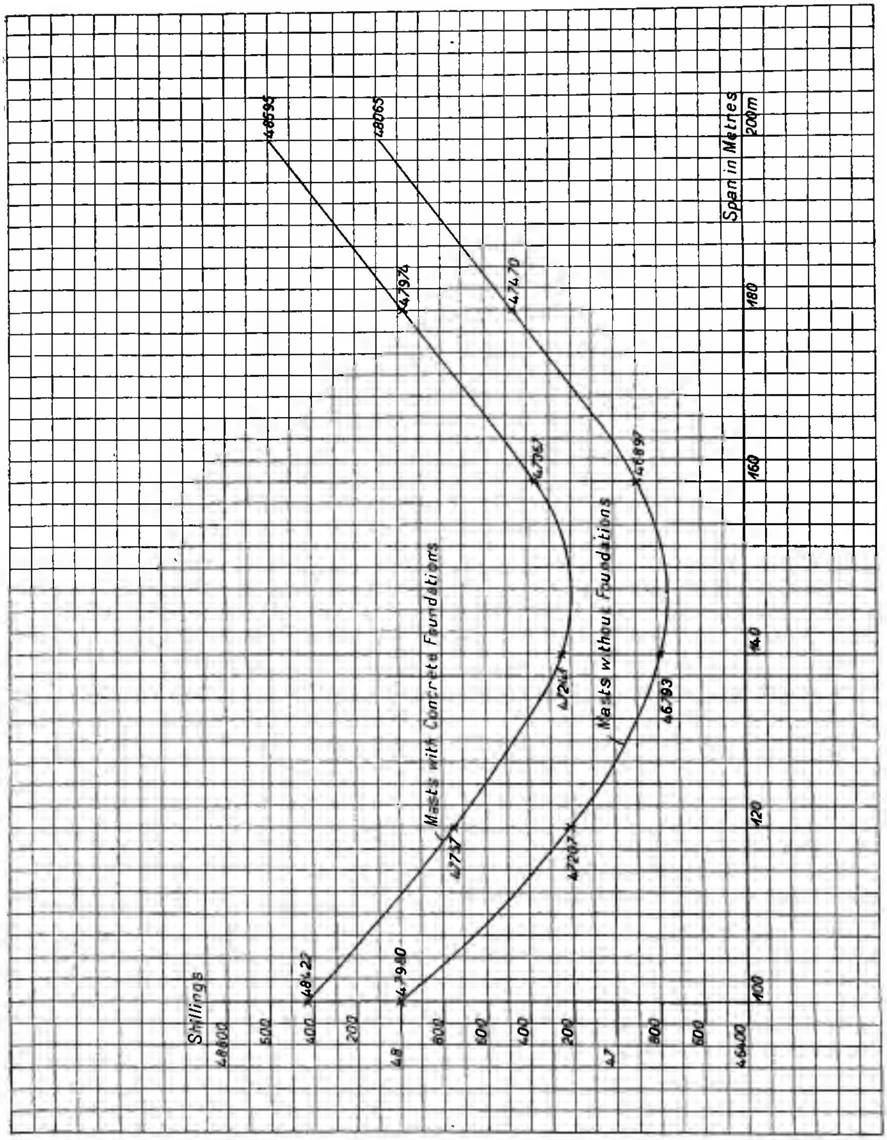

Span in Metres
Masts with Concrete Foundations
Masts without Foundations
Shillings

Fig. 230.

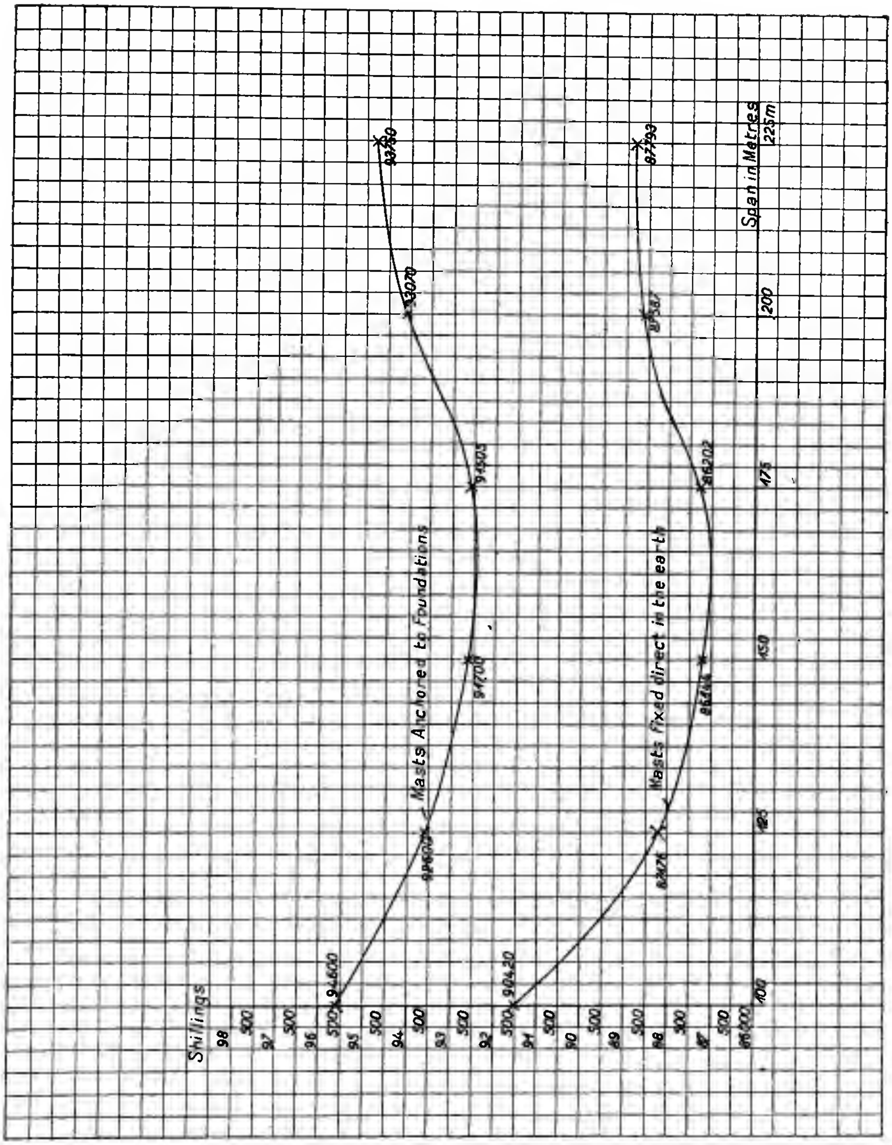

Shillings
Span in Metres
Masts Anchored to Foundations
Masts fixed direct in the earth

Fig. 231.

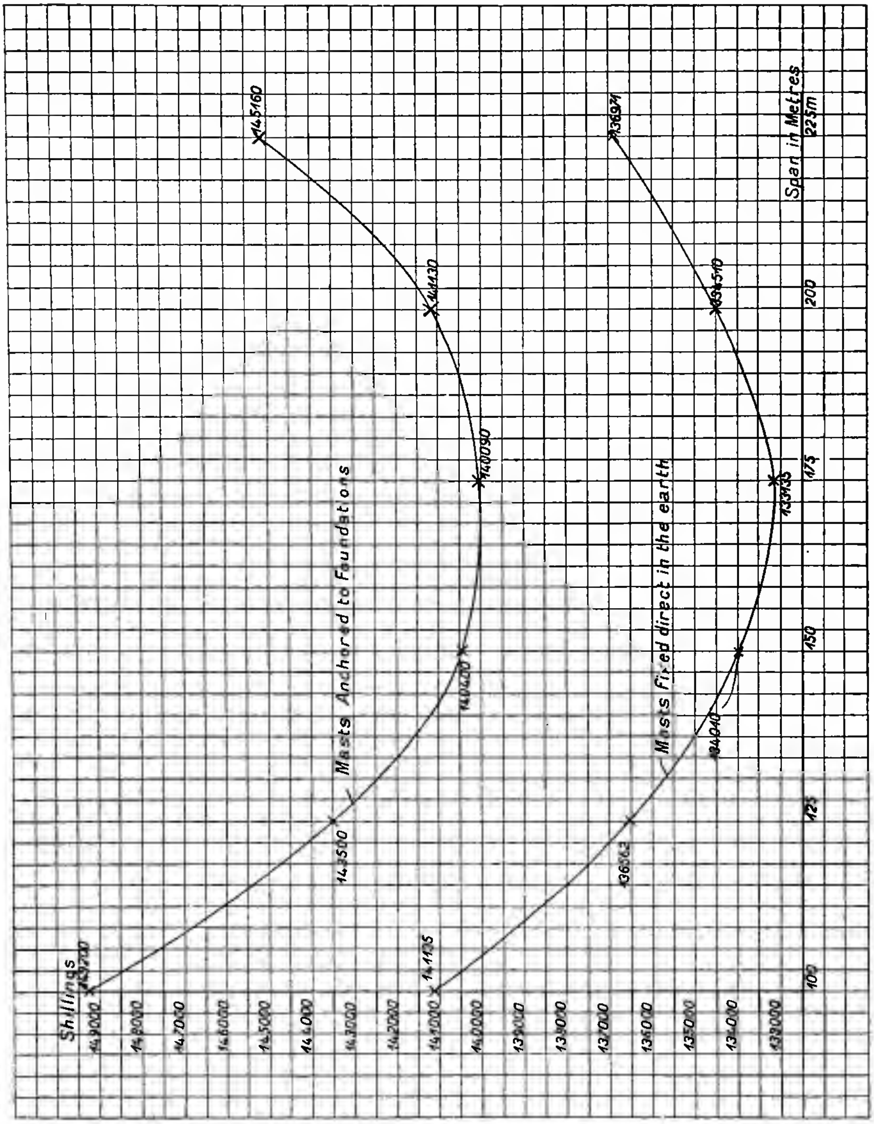

Masts Anchored to Foundations
Masts fixed direct in the earth
Shillings
Span in Metres
100
125
150
175
200
225m

Fig. 232.

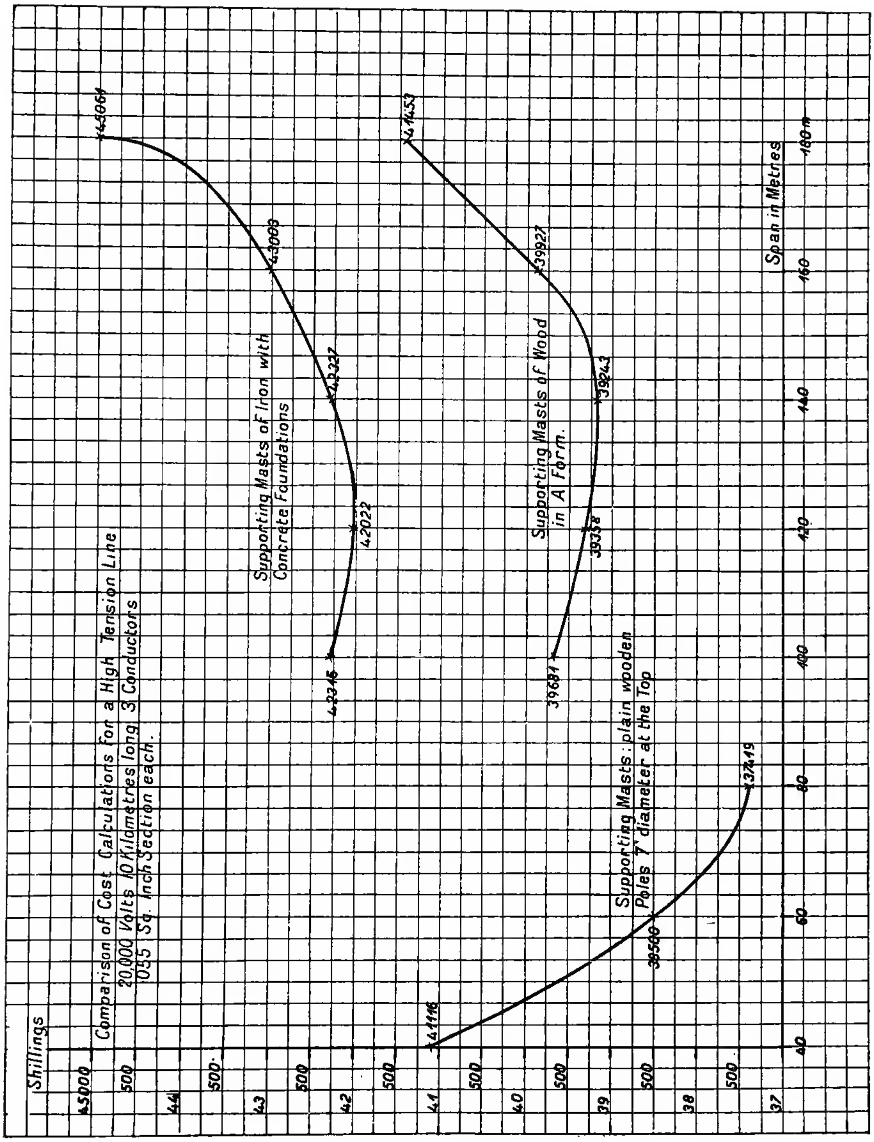

Shillings
Comparison of Cost Calculations for a High Tension Line
20,000 Volts 10 Kilometres long 3 Conductors
·055 Sq. Inch Section each.
Supporting Masts of Iron with Concrete Foundations
Supporting Masts of Wood in A Form.
Supporting Masts: plain wooden Poles 7" diameter at the Top
Span in Metres
43061
43003
42327
42022
42345
41453
39927
39243
39358
39681
41116
38560
37419
45000
500
44
500
43
500
42
500
41
500
40
500
39
500
38
500
37
40
60
80
100
120
140
160
180 m

Fig. 233.

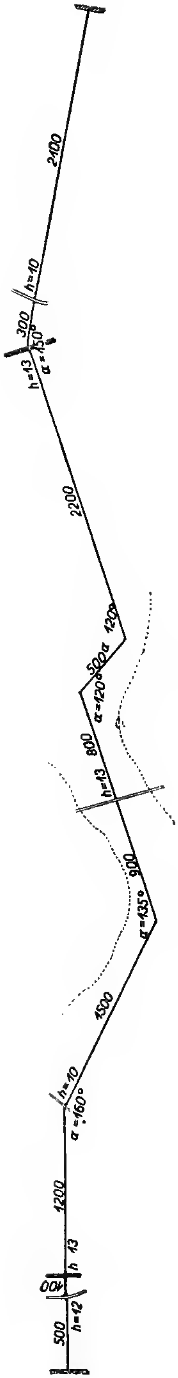


Fig. 234.

As a further example of the effect of the length of the span on the first cost of the line the case of a 20,000-volt three-phase line, whose plan is shown in Fig. 234, is worked out in Table 41. There are three copper wires each of ·055 square inch section. The strain masts and corner masts are of lattice-work, and the road and rail crossings are carried out as special safety suspensions (factor of safety of 5). Three types of supporting masts are considered, viz.,

(1) Plain wooden poles, 7 inches diameter at the top ;
(2) Wooden poles of A form ;
(3) Iron masts with concrete foundations.

The maximum stress on the copper wires is taken as 23,000 lbs. per square inch.

The loads falling on the various masts are as follows :—

Length of Span in Metres.	Load per Mast in lbs.			
	Supporting Masts.	Angle Masts for Angles of 120°.	Angle Masts for Angles of 135°.	Strain Masts.
40	178	3,720	2,850	3,720
60	265	3,720	2,850	3,720
80	356	3,720	2,850	3,720
100	445	3,720	2,850	3,720
120	530	3,720	2,850	3,720
140	620	3,720	2,850	3,720
160	710	3,720	2,850	3,720
180	800	3,720	2,850	3,720

TABLE 41.—*First Cost of the H.T. line shown in Fig.* 234, *consisting of* 3 × ·055 *square inch copper wires for* 20,000 *volts.*

Cost in Shillings of :

Supportiog masts complete with Cross-arms and Insulators.	Angle Masts complete with Cross-arms and Insulators.	Strain Masts complete with Cross-arms and Insulators.	Railway Crossings complete with Cross-arms and Insulators.	Road Crossings complete with Cross-arms and Insulators.	Copper Wires.	Erection.	Total for the 10 Km.
Span = 40 metres (130 feet). Supporting masts plain wood poles 7 metres high above ground.							
8,507	783	819	3,790	6,517	17,400	3,300	41,116
Span = 60 metres (196 feet). Supporting masts plain wood poles 7·5 metres high above ground.							
5,806	853	894	3,790	6,517	17,400	3,240	38,500
Span = 80 metres (260 feet). Supporting masts plain wood poles 8·2 metres high above ground.							
4,675	913	944	3,790	6,517	17,400	3,180	37,419
Span = 100 metres (326 feet). Supporting masts of A form (wood) 9 metres high above ground.							
6,749	1,025	1,080	3,790	6,517	17,400	3,120	39,681
Span = 100 metres (326 feet). Supporting masts of iron 9 metres high above ground.							
9,384	1,025	1,080	3,790	6,517	17,400	3,120	42,316
Span = 120 metres (395 feet). Supporting masts of A form (wood) 10 metres high above ground.							
6,134	1,206	1,251	3,790	6,517	17,400	3,060	39,358
Span = 120 metres (395 feet). Supporting masts of iron 10 metres high above ground.							
8,798	1,206	1,251	3,790	6,517	17,400	3,060	42,022
Span = 140 metres (460 feet). Supporting masts of A form (wood) 11 metres high above ground.							
5,523	1,351	1,401	3,790	6,778	17,400	3,000	39,243
Span = 140 metres (460 feet). Supporting masts of iron 11 metres high above ground.							
8,607	1,351	1,401	3,790	6,778	17,400	3,000	42,327
Span = 160 metres (525 feet). Supporting masts of A form (wood) 12·2 metres high above ground.							
5,516	1,525	1,590	3,790	7,166	17,400	2,940	39,927
Span = 160 metres (525 feet). Supporting masts of iron 12·2 metres high above ground.							
8,592	1,525	1,590	3,790	7,166	17,400	2,940	43,003
Span = 180 metres (590 feet). Supporting masts of A form (wood) 13·5 metres high above ground.							
5,453	1,790	1,870	4,020	8,040	17,400	2,880	41,453
Span = 180 metres (590 feet). Supporting masts of iron 13·5 metres high above ground.							
9,061	1,790	1,870	4,020	8,040	17,400	2,880	45,061

The results of Table 41 are shown in the form of Curves in Fig. 233.

23. COMPARISON OF THE VARIOUS SUPPORTING STRUCTURES WITH REFERENCE TO MINIMUM ANNUAL CHARGES.

For a given type of support the problem of minimum first cost is solved when the "economical span" has been discovered as described above, but the question as to minimum annual outlay has not yet been dealt with. This annual outlay is made up of interest on the capital laid out, sinking fund charges, depreciation, maintenance and repair allowance, and any rents paid out to owners for wayleaves. When the sum of these charges is a minimum the most economical arrangement has been arrived at.

As an example, the annual charges for the case dealt with in Table 41 and Fig. 233 will now be worked out. Interest will be allowed for at the rate of 5 per cent. The whole of the capital cost is to be paid off in thirty years, which means an amortisation allowance of 1·79 per cent. if interest at the rate of 4 per cent. is allowed on the written-off amounts.

The average life of Kyanised wooden poles may be taken as fifteen years. A double coat of paint will have to be given to all iron parts at intervals of three years. Replacements owing to lightning strokes and mechanical effects will amount to ·5 per cent. annually in the case of wooden poles and to 2 per cent. annually for insulators. The values estimated on this basis are collected in Table 42 and Fig. 235. The curves show that the variations in annual charges change with the length of span in much the same way as the variation in first cost. This is due to the fact that the allowances for interest and sinking fund are generally much more important than the other annual charges, so that the latter hardly enter into the question of minimum annual cost if the work is reasonably well carried out.

Although reduced first cost affects the dividend-earning power of the line favourably, it is a mistake to obtain the reduction by the use of poor materials or workmanship, as the increased attention and repair work and the shorter life involve annual outlays which may well exceed the saving in interest.

It has already been pointed out that æsthetic considerations also often make it necessary to exceed the absolute minimum cost of installation and even the minimum demanded by good workmanship. This is confirmed by the above example. It will be seen that the minimum annual charges if iron lattice masts are used occurs with a span of 120 metres, but the increase for a span of 160 metres is quite small, so that the longer span should certainly be used as often as practicable. Not only will the electrical and mechanical security be improved, but the trouble for wayleaves, owing to the reduced number of supporting points, will also be diminished, a straighter run of line will be possible, and the long spans and slight, flexible masts will æsthetically improve the general effect and be less likely to be called in question by lovers of the countryside.

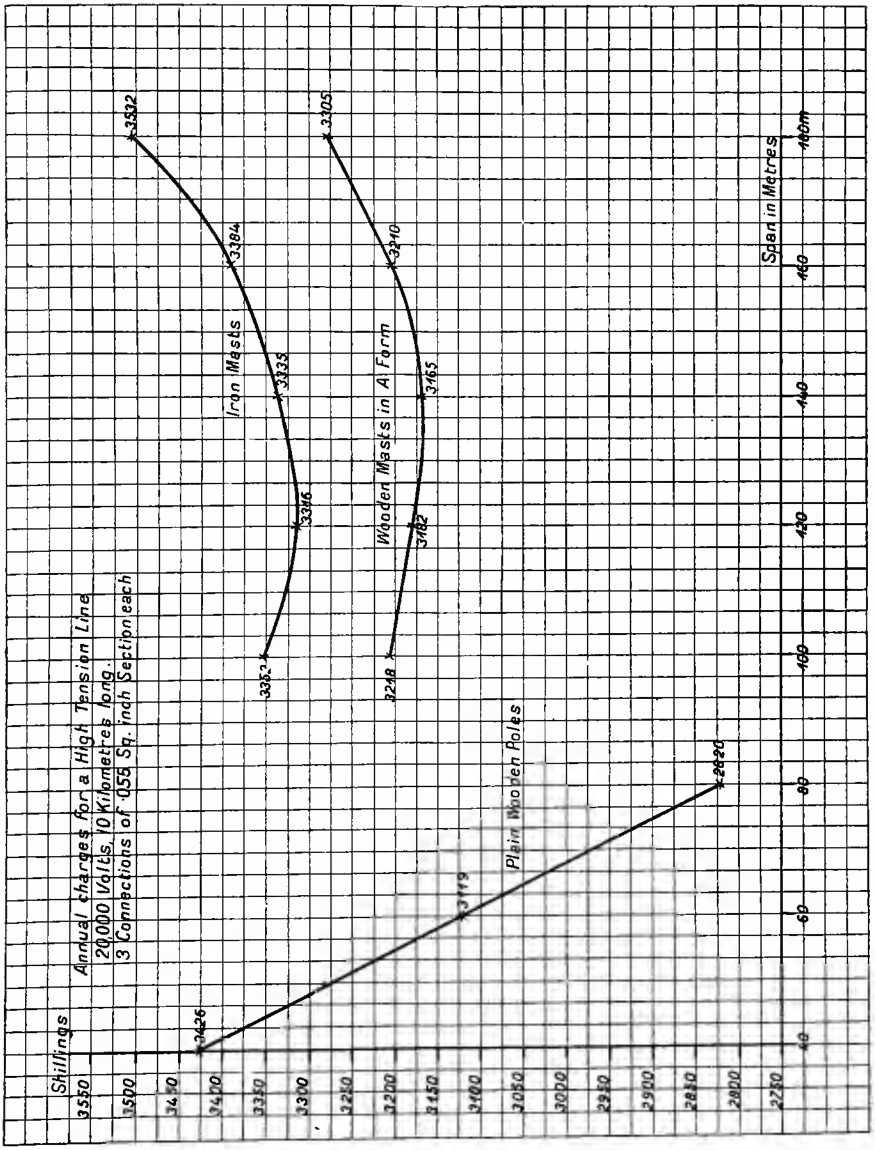

Annual charges for a High Tension Line
20,000 Volts, 10 Kilometres long.
3 Connections of ·055 Sq. inch Section each
Shillings
3550
3500
3450
3400
3350
3300
3250
3200
3150
3100
3050
3000
2950
2900
2850
2800
2750
Iron Masts
3532
3384
3335
3316
3352
Wooden Masts in A Form
3305
3210
3165
3182
3218
Plain Wooden Poles
3426
3119
2820
Span in Metres
40
60
80
100
120
140
160
180m

Fig. 235.

TABLE 42.

Span in Metres:	40	60	80	100	120	140
Types of Supporting Mast:	Plain Wooden Poles.			Wooden Poles of A Form.		
In Shillings. Interest at 5 per cent.	2,055·8	1,925	1,870·95	1,984·05	1,967·9	1,962·15
Sinking fund at 1·79 per cent.	735·97	689·15	669·8	710·19	704·5	702·45
Maintenance	421·2	315	271·5	345	337	331
Repairs	213	190	175	179	173	169
Total annual charges	3,425·97	3,119·15	2,820·25	3,218·24	3,182·4	3,164·6

Span in Metres:	160	180	100	120	140	160	180
Type of Supporting Mast:	Wooden Poles of A Form.		Iron Lattice Masts.				
In Shillings. Interest at 5 per cent.	1,996·35	2,072	2,115	2,101	2,116	2,150	2,253
Sinking fund at 1·79 per cent.	714·69	742	757	752	757	769	806
Maintenance	334	329	320	308	310	317	330
Repairs	165	161	159	155	151	147	143
Total annual charges	3,210·04	3,304	3,351	3,316	3,334	3,383	3,532

24. LOCAL OVERHEAD DISTRIBUTING SYSTEMS.

General Considerations.

The underlying principles laid down for overhead transmission lines also apply to overhead installations for the distribution of electrical energy within an inhabited district. Here, however, the æsthetic point of view is of greater importance. The amenities of the street must be interfered with as little as possible by unsightly structures or wire crossings at all sorts of levels.

This point of neat appearance cannot be insisted upon too strongly. The way in which village streets and attractive bits of scenery are often spoilt by overhead lines or "artistic" supporting structures* is deplorable. Even the most beautiful relics of the old-time architects are sometimes placed under contribution by the modern overhead line constructor. Walls and roofs are used indiscriminately to carry his wire supports, and in order that these signs of the modern spirit shall not be overlooked they are often placed well in the foreground and in the best light. There are, of course, cases in which it is impossible to avoid using buildings of historical or artistic interest as supports or, at any rate, erecting supports close to them. The greatest care should, however, be taken to make the new structure match the old as far as technical considerations permit.

In the great majority of cases the arrangements can be carried out so as to meet the reasonable requirements of people of artistic susceptibility. This can be best done by running the line as far as possible out of sight, at the backs of buildings or roofs, on roof or wall brackets, and placing the wooden or iron poles in yards or gardens. As this generally involves additional expense, owing to the increase in the necessary length of wire, the engineer is often faced with a somewhat difficult task.

Another point to be considered is the question of line supervision and maintenance. If the lines are erected out of sight at the backs of houses and so on, it is evident that they cannot be so easily supervised, and faults will not be so readily discovered and put right as if the lines were run openly along the streets. On the other hand, such lines are less open to malicious damage or damage through traffic.

The danger from atmospheric effects is in any case slight and need not be considered.

Another disadvantage of running wires over or through inhabited property is the difficulty of regular access for repair or alteration work. In some agricultural districts houses are shut up all day whilst the workers are in the fields, and this often delays work on the lines. These difficulties have, however, to be allowed for in any case when wires are supported on roof structures.

* Postal wires are often as objectionable from this point of view as power lines.

Careful arrangement of the line and selection of the positions of the supporting points, especially the distributing and branching points, will generally enable the whole to be designed to suit the look of the streets and to cause little disturbance to their appearance. Exactly how to proceed in any particular case is not so easily explained, and must be left to the dictates of experience combined with artistic sensibility and a love of the subject. One other point must be referred to in this connection. After a satisfactory installation has been erected by a careful consideration of appearance so far as funds will permit, precautions must be taken to ensure that future extensions shall be carried out in the same spirit.

Fig. 236.

Careful maintenance and repair of the line and its supports are great aids to appearance and also tend to keep the whole in good order technically.

The various methods of support may be classified as :

(*a*) Wooden or iron masts ;
(*b*) Iron roof standards ;
(*c*) Iron wall brackets.

(*a*) *Wooden Poles.*—These are the cheapest form of support for a distributing network if the insulators are carried on bent brackets screwed directly into the wood. If the line is erected along the streets the cost of house services and street lamp connections and connections to portable motors will also be low.

The supporting points are easy of access and section switches and fuses are easily reached. The chief disadvantage is the interference with the appearance of the streets, and this is little improved even if light cross-arms with straight insulator pins are used and the wooden poles are painted and decorated.

If the wooden poles are placed in yards and gardens behind the houses the street is freed from all supporting structures and also from all wires, if lines are run at the backs of both rows of houses. The increase in cost of house connections is only slight, but the connections for street lamps and portable motors are decidedly longer and dearer. Other disadvantages are the dependence on private owners and the need for tall masts in order to bridge the trees found in most gardens.

Fig. 237.

Iron poles would only be employed in exceptional cases, where it is impossible to erect the line anywhere but in the street and yet where something more permanent and more graceful than wooden poles is desired. In such cases tubular

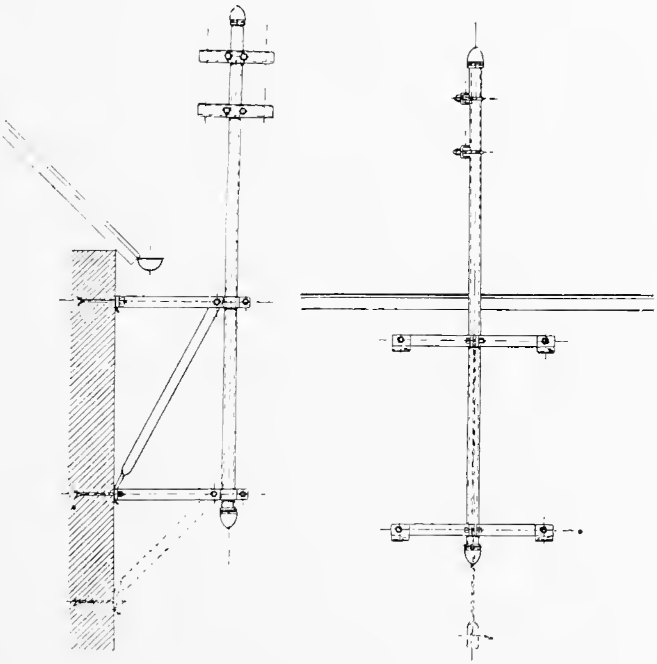
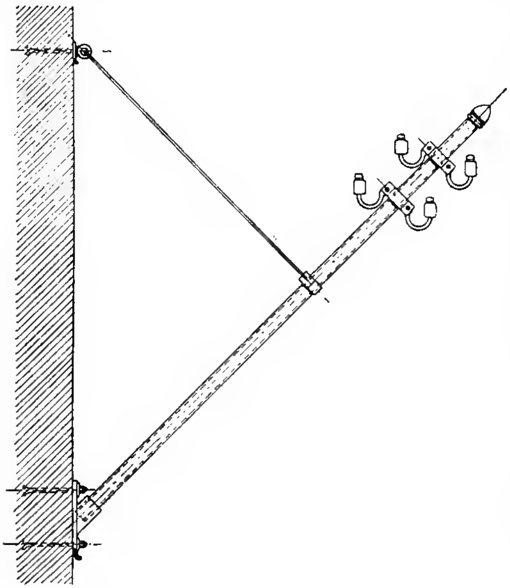


Fig. 238.

masts (Fig. 236) should be used, covered with sheet zinc up to a height of about 2 feet from the ground to protect them from dogs.

(*b*) *Iron roof standards* (Fig. 237) are very commonly used. They should be so situated that the wires are out of the reach of persons on the roof or on outhouses or at windows. This means that the lines should be kept at least 5 or 6 feet from the house at all points. The installation is more expensive than that of wooden poles, and the connections for street lamps are longer. Access to the wires depends on the householder's habits. Maintenance is somewhat expensive, owing to the effect of the fine ash given off from the neighbouring chimneys on the paint. The maintenance of the roof structure may also involve expense, especially if it has not been properly strengthened in the first instance.



If road crossings are to be avoided lines must be run on both sides of the roads and should be placed at the back of the roofs, as far out of sight as possible.

(*c*) *Iron wall brackets or standards* are carried out in a great variety of forms. Sometimes they consist of iron tubular poles set vertically (Fig. 238) and sometimes they are arranged, like flag poles, on the slant (Fig. 239). Both these are hideous arrangements and should only be permitted in exceptional cases. The simplest form consists of an iron tube projecting horizontally from the wall (Fig. 240). This is especially suitable where the line of buildings is all at approximately the same elevation (Fig. 241). The supports can be reached from the roadway, and the connections both to the houses and to the street lamps are short. The cost is as low as for wooden poles. The appearance is only good so long as all the arms are at practically the same level and the wires can be run straight along. When this rule is not adhered to deplorable results, such as those shown in Fig. 242, are obtained.

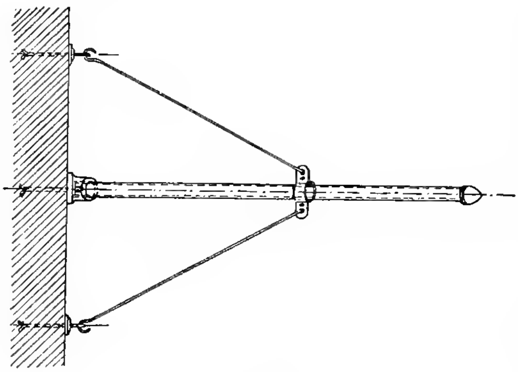


Fig. 239.

Determination of the Positions of the Supporting Points.

The rule laid down for transmission lines of reducing the number of insulators to a minimum can receive only scant attention in the case of distributing net-

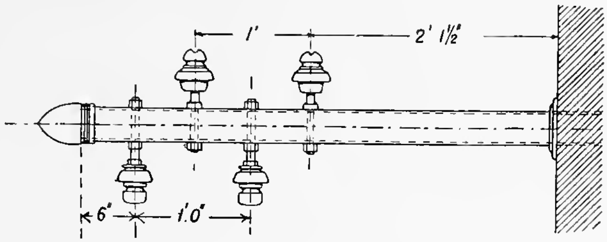


Fig. 240.

works. In this case, too, it is not so important because numerous insulators do not diminish the security appreciably but only add to the expense. The separate house services, the street lamp positions, the positions of plugs for

Fig. 241.

portable motors, and the positions of suitable houses for fixing the supports to, determine the number and positions of the latter. The average separation between supporting points when bare wires are used is 35 or 40 yards, and for insulated cables, which require more sag, 25 to 30 yards. Masts and poles must be so placed that they do not interfere with the street traffic and do not block entries.

If placed at the edge of the curb they must be protected by buttress stones from damage by vehicles. If the portion of the roadway on which the masts are to be placed is private property, special permission to use it must, of course, be first obtained. Care must be taken not to let the wires approach too closely to windows.

In selecting positions for roof standards public buildings or those in possession of the local authorities should be used wherever possible. When private houses have to be used those should be selected which have about the same height and the same robustness of structure. Special care must be used when deciding on the buildings to carry corner masts and those at distributing points in the line so that the roof and walls may have ample strength to bear the stresses. These buildings should be such as are easy of access at all times.

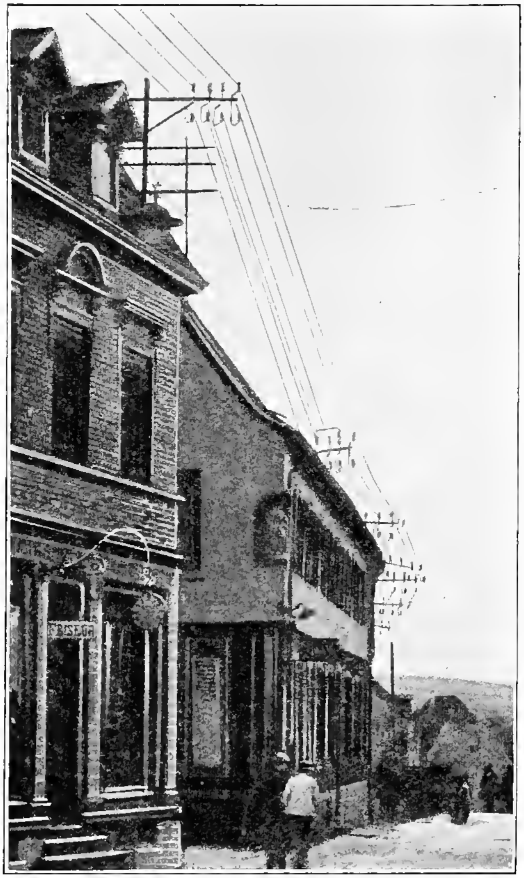


Fig. 242.

Where the distributing system is one working with an earthed wire the iron parts of the roof standards must be connected with this wire. The building is then protected against lightning, and this fact can sometimes be made good use of in obtaining permission for erecting the standard. The necessary permission is also more easily obtained from a householder who is himself a consumer.

The supports should not be connected to chimneys, and the wires should not be taken over or near to them, because the smoke contains sulphurous fumes which attack the copper. Roof structures should not be stayed to or mounted on party-walls, as the humming of the wires is liable to be carried down to the lower stories.

Wall brackets and arms should be so placed that the lines are at least 16 feet from the ground. Plenty of clearance from windows should also be allowed.

Party-walls may be used as supports for wall brackets or arms, as wires mounted on these are not subject to humming trouble. The construction must permit whitewashing or other repair work to be carried out without danger.

The wires should be run as straight as possible, and not carried zig-zag across roads or houses, as is so often done with telephone wires. Points of inflection in either the horizontal or the vertical plane diminish the security and have a bad appearance. On the supports the wires must be arranged so as to avoid crossings as far as possible, the heavier wires being placed lowest and the earthed wire nearest the top, as the latter somewhat protects the rest of the lines against atmospheric effects. The arrangement should permit of the connection for the distribution wires being easily and conveniently carried out.

Constructional Material.

Roof standards, wall standards, and wall arms are made of wrought-iron pipes or of Mannesmann weldless steel tubing. The maximum working stress for the wrought-iron pipes is about 21,500 lbs. per square inch and for the steel tubing about 29,000 lbs. per square inch. The usual tube diameters are 3 and 3½ inches outside (+ an allowance of ·04 inch), and the thickness of wall is ·12 or ·2 inch within about 10 per cent. The thinner tubes are used for straight stretches and the thicker ones at curves or distributing points or on straight stretches with heavy lines.

Table 43 shows the allowable top pulls for various lengths of standards made of these tubings.

Table 44 shows approximately the number and size of wires that can be mounted on roof standards of various lengths without exceeding the above pulls, the pull considered being that due to wind pressure and the length of span being taken as 115 feet.

Table 43.

Outside Diameter in Inches:—		3½	3	3½	3	3½	3	3½	3
Thickness of Tube Wall in Inches:—		·12	·12	·2	·2	·12	·12	·2	·2
Material:—		Iron.				Steel.			
Resisting Moment of Section in Inches^3:—		1·02	·77	1·64	1·14	1·02	·77	1·64	1·14
Allowable pull at the top in lbs. with standards having free lengths of:—	5 feet	355	265	590	405	480	355	790	550
	6½ feet	260	195	430	300	350	260	580	400
	8 feet	205	152	340	255	300	205	460	315
	10 feet	160	117	270	183	222	160	370	260

TABLE 44.

Material:—	Iron.				Steel.			
Outside Diameter in Inches ;—	3½	3	3½	3	3½	3	3½	3
Free Length of Standard in feet.	Number and Cross-section (square inches) of the Wires.							
5	6 × ·078	4 × ·078	6 × ·148	4 × ·187	6 × ·108	6 × ·078	8 × ·186	5 × ·148
	3 × ·108 1 × ·039 2 × ·0155	3 × ·078 1 × ·025 2 × ·0155	3 × ·186 3 × ·108 —	3 × ·148 1 × ·054 2 × ·025	4 × ·078 2 × ·054 2 × ·039	3 × ·108 1 × ·039 2 × ·0155	6 × ·186 4 × ·108 —	3 × ·148 3 × ·078 1 × ·054
6½	4 × ·078	3 × ·078	4 × ·148	4 × ·108	6 × ·078	4 × ·078	6 × ·148	4 × ·187
	3 × ·078 1 × ·025 2 × ·0155	2 × ·054 — 2 × ·0155	3 × ·078 3 × ·054 —	3 × ·054 1 × ·039 2 × ·0155	3 × ·108 1 × ·039 2 × ·0155	3 × ·078 1 × ·025 2 × ·0155	3 × ·187 3 × ·108 —	3 × ·148 1 × ·054 2 × ·025
8	3 × ·078	3 × ·054	4 × ·148	3 × ·108	4 × ·078	3 × ·078	6 × ·108	4 × ·108
	3 × ·054 3 × ·0155 —	3 × ·039 1 × ·0155 —	3 × ·078 3 × ·054 —	3 × ·078 1 × ·039 —	3 × ·078 1 × ·039 1 × ·0155	3 × ·054 — 3 × ·0155	4 × ·078 1 × ·054 2 × ·039	3 × ·054 1 × ·039 2 × ·025
10	4 × ·039	3 × ·039	4 × ·078	3 × ·078	3 × ·108	4 × ·039	6 × ·078	4 × ·078
	3 × ·039 1 × ·025 —	3 × ·025 1 × ·0155 —	3 × ·078 1 × ·039 1 × ·0155	3 × ·054 2 × ·0155 —	3 × ·078 1 × ·039 —	3 × ·039 1 × ·025 —	3 × ·108 3 × ·054 —	3 × ·078 1 × ·025 2 × ·0155

The tops of these tubular standards are usually protected against rain and given a more finished appearance by means of a metal (zinc) cap (Fig. 243). The cap must be pushed well on to prevent it being blown off by the wind.

The point where the standard passes through the roof must be rendered water-tight. For this purpose the tube can be surrounded by a pair of sheet metal cones (Fig. 244), one of which is interleaved with the tiles on the roof in a water-tight manner and projects upwards under the other cone, which is itself attached by a water-tight joint, packed with leather, to the standard.

If the standard passes through the roof ridge the arrangement shown in Fig. 245 is adopted.

The standard is attached to the roof beam by means of bolts running right through and bedding against large washers. The cleats used, owing to the slope of the beams, must be shaped on the slant as shown in Fig. 246.

Direct attachment to a single beam is only permissible with very heavy beams. Usually a cross-beam should be inserted, bolted to three or four of the roof beams, and to this the standard should be cleated (Figs. 247 and 248).

With weak roof structures strengthening cross-beams must be inserted and securely bolted up by bolts passing right through the beams (see Figs. 249 and 250).

If it is found that the humming of the wires is transmitted objectionably to the building all the points of contact between the standard and the building, as well as all the points where cross-arms, stays, or struts are attached, must be packed with a layer of felt, rubber, or lead.

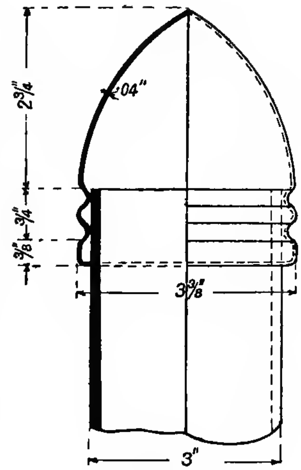


Fig. 243.

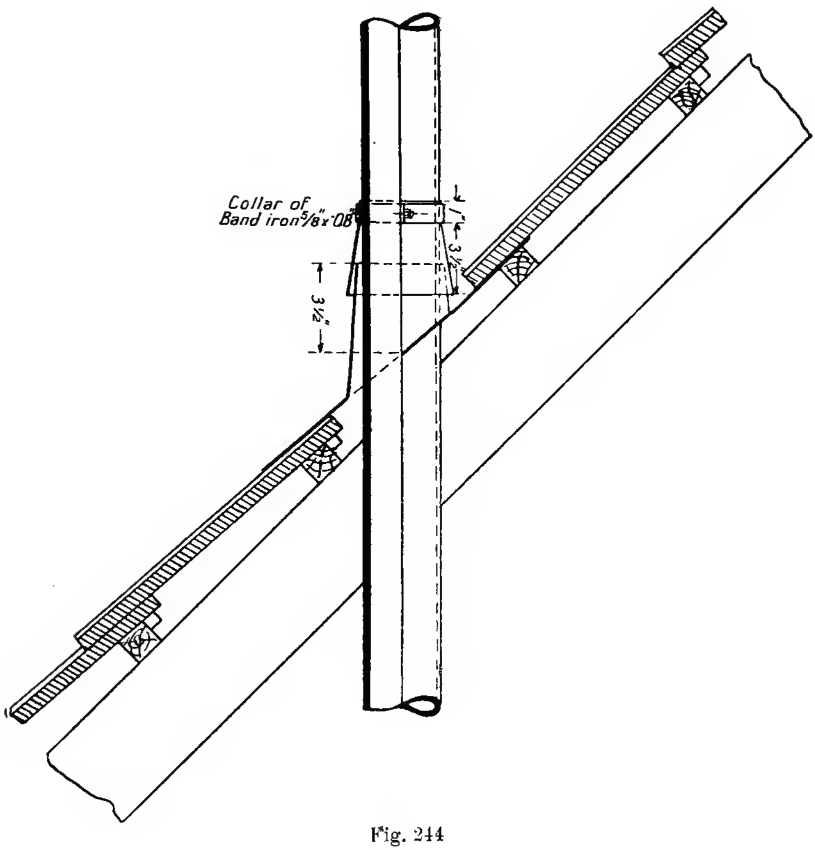


Fig. 244

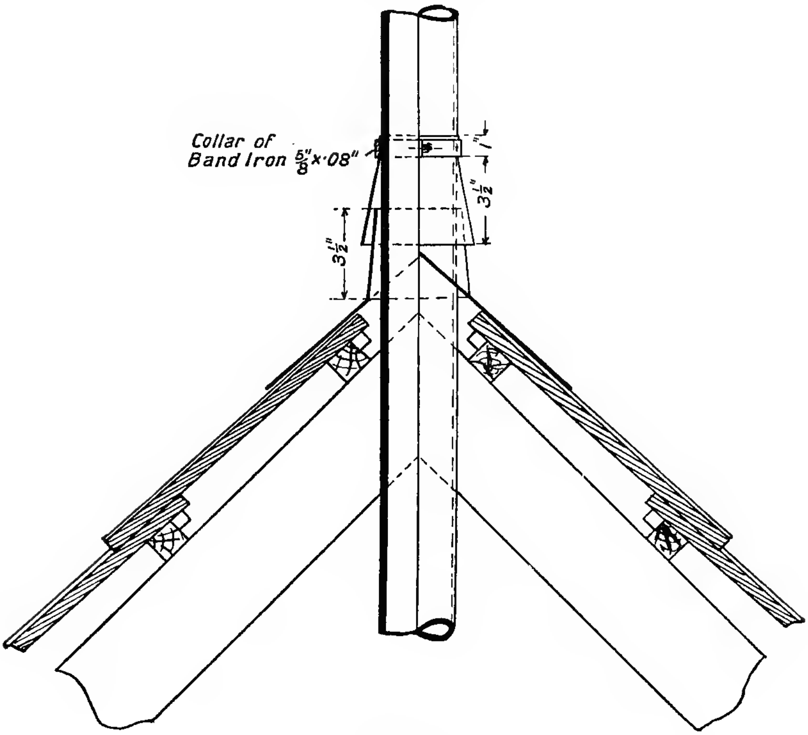


Fig. 245.

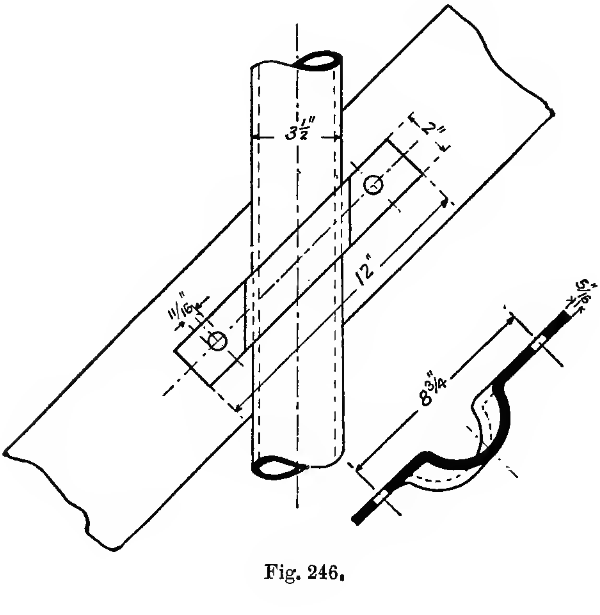


Fig. 246.

At the more important supports, especially those at distributing points and crossing points, convenient trap-doors should be provided in the roof to facilitate inspection. These should have an opening of 20 to 30 inches and consist either of a cast-iron frame with wrought-iron glazed cover or of a wooden frame about 4 inches high and provided with a sheet-zinc-covered door.

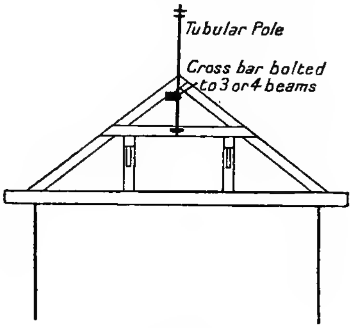


Fig. 247.

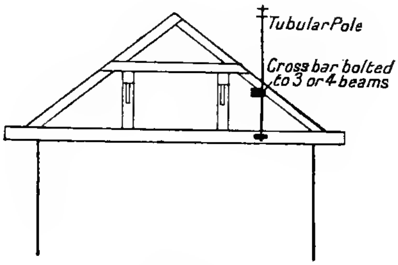


Fig. 248.

Roofs carrying a number of wires should be provided with boards laid between the trap-door and the standard to avoid damage.

Where the height of the standard is more than about 5 feet, standing boards or steps, as shown in Fig. 251, should be fitted for convenience in the erecting work.

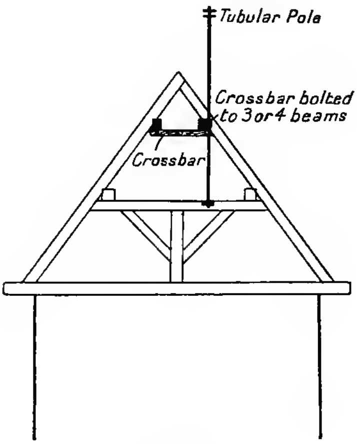


Fig. 249.

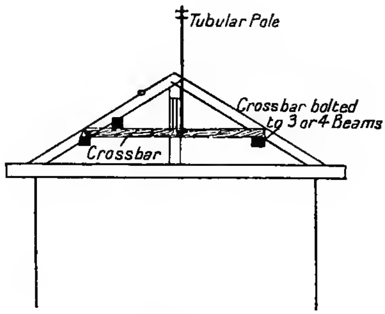


Fig. 250.

The boards should be removed for appearance' sake after the work is completed, but a few of them should be kept handy for future use in repair work, etc. A standing board arranged for ready interchange is shown in Fig. 252. In this case a collar with two projecting lugs is permanently fitted to the standard, and the standing board is slipped over these when required.

Two methods of attaching standards to walls are shown in Figs. 238 and 239.

Drip arrangements should be fitted under the bolts on the walls to prevent discoloration.

Wall-arms (Fig. 240) can be fixed direct in the wall with cement mortar if the thickness of the wall is 15 inches or more. With thin walls the tubular arm should be extended inwards and attached to the roof beams (Fig. 253).

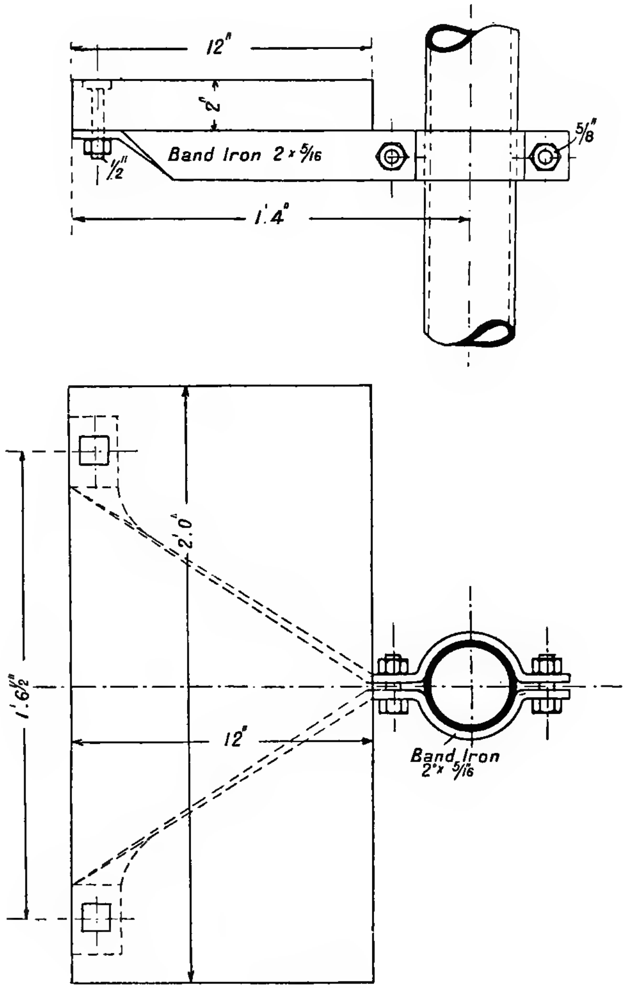


Fig. 251.

Damage done to the plaster surface should be covered by an ornamental galvanised iron disc.

Figs. 254 and 255 show methods of attaching horizontal arms to roofs.

When struts are required for additional support they are made of angle, T, or I section. Stays or guy ropes may consist of round iron or of galvanised iron wire ropes made up on the spot out of from two to five strands of wire about

·14 inch in diameter. The stays can be attached to beams, as shown in Fig. 256, by means of hooks like Fig. 257, bolted on. Water-tight joints are made on stays where they pass through the roof in the same way as on standards. Struts of sectional iron are not so easy to deal with in this way, so that where struts have

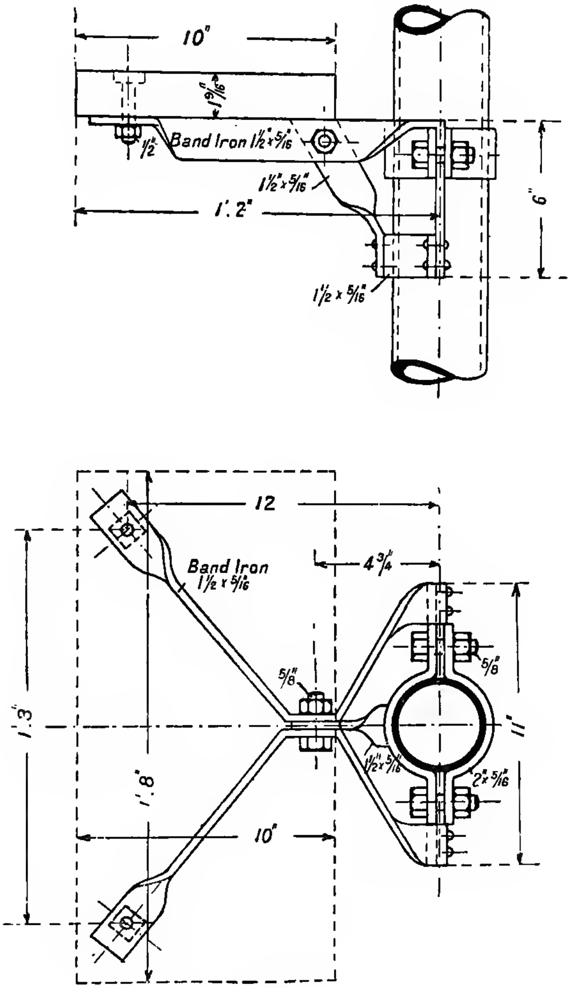


Fig. 252.

to pass through a roof they are preferably made of tube, and the ends are either hammered flat or are provided with proper supporting end pieces.

The cross-arms are commonly made of bar iron or channel iron. Bar iron arms, as shown in Figs. 258 to 260, are somewhat lighter than those of channel iron (Fig. 261). The type shown in Figs. 259 and 260 has the æsthetic advantage that the centre of the insulators lies in the same plane as the centre of the pole.

Sometimes collars to which bent (swan-neck) insulator pins are attached

are used. This, however, is a more expensive arrangement and, owing to the weakness of the bent pins, is not suitable for angle points. Bar iron or channel iron cross-arms or tubular wall-arms are especially convenient if the insulators

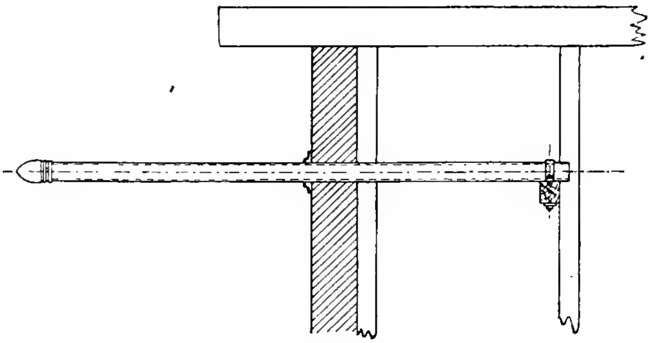


Fig. 253.

have to be used in an inverted position (Fig. 277). The insulator is mounted on its pin with hemp as usual, and the mouth is then closed with a lead disc held in position by a nut so as to prevent water penetrating. The different arrangements are shown in Figs. 240, 261, 277, and 280.

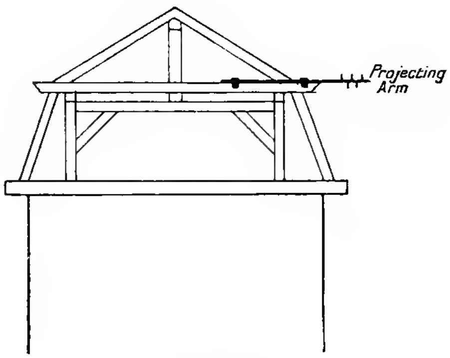


Fig. 254.

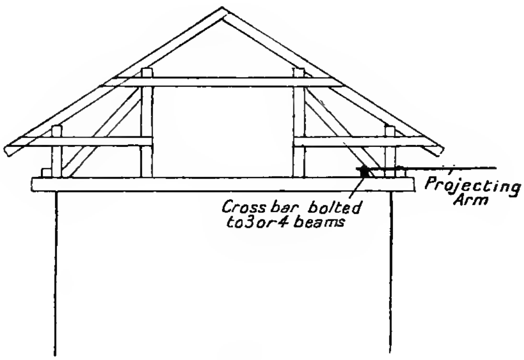


Fig. 255.

If, as is sometimes the case, it is necessary to place an insulator at the top of a tubular standard an adapter having a $\frac{3}{4}$ or $\frac{1}{2}$ inch tapped hole for the pin is screwed on to the top of the standard. A method of fixing an insulator at the top of a wooden pole is shown in Fig. 86.

Working on Roofs.

When work is about to begin warning placards should be put up in the neighbouring streets, yards, etc., or other means should be adopted for notifying

passengers of danger from falling objects, etc. Where a considerable amount of work has to be carried out protecting sheets should be erected. Any police regulations or local bye-laws applying to such work should be strictly complied with.

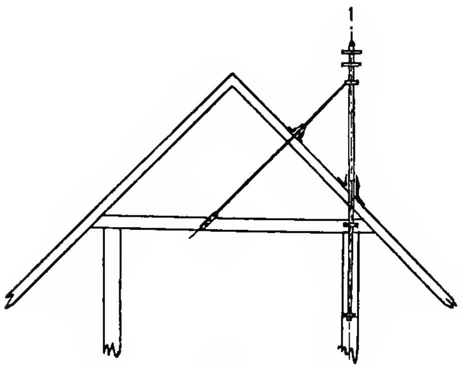


Fig. 256.

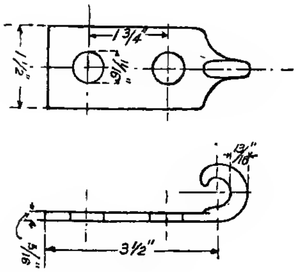


Fig. 257.

Men working on roofs or masts should be provided with safety belts. When soldering work has to be carried out in or on houses, great care must be exercised. Blow-lamps must not be lighted in lofts or on roofs. The amount of opening-

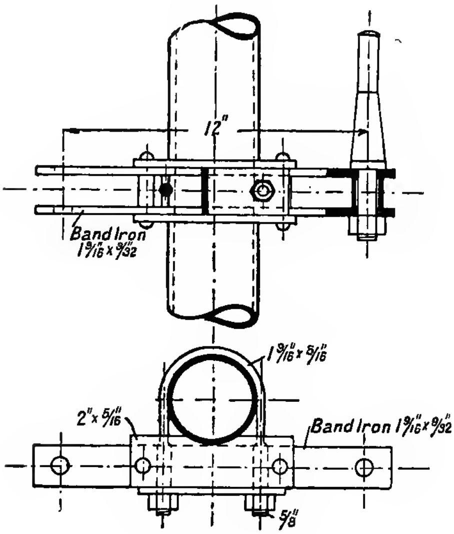


Fig. 258.

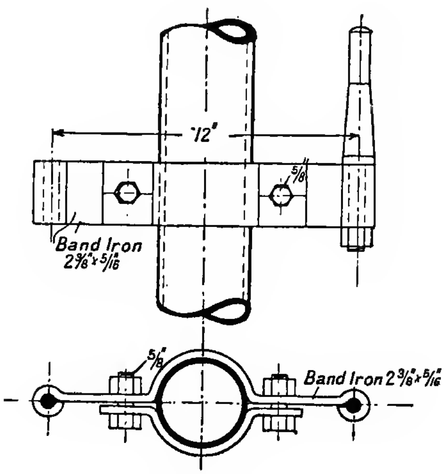


Fig. 259.

up of the roof should be reduced to a minimum, and any openings made should be carefully protected from rain when work ceases and during the night.

Material must only be hauled up on the outside of a house after all necessary steps to protect the walls and roof from damage have been taken.

The wires should only be put up after all stays, struts, etc., have been fitted. At corner points and distributing points, where the staying has to be done in a direction counteracting the resultant pull, temporary additional stays are put up

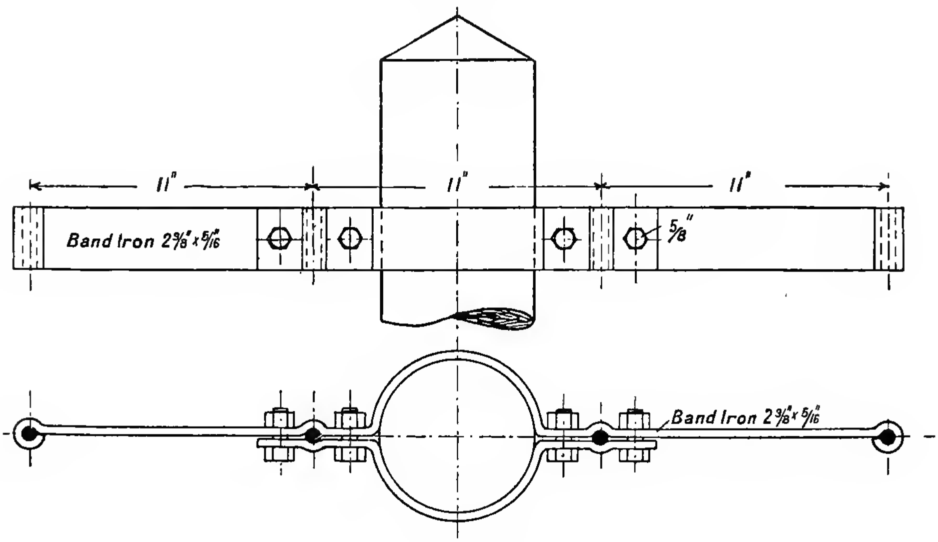


Fig. 260.

with ropes and pulley blocks until after all the wires have been erected, when the pull will fall in the correct direction.

In order to raise the wires into position a rope is first thrown over the standard and the first wire, together with the start of a second rope, are attached to the end of the first rope. This is then drawn up until the first wire reaches the standard. Then the second rope is used to draw up the second wire, together with a third rope, and so on, until all the wires have been got up. If a large number of wires have to be dealt with it will save time to fix up an endless rope passing over a pulley on the ground and another on the roof. Pulleys or rollers (Figs. 210 and 211) should be provided close to the insulators for drawing the wires over without damage.

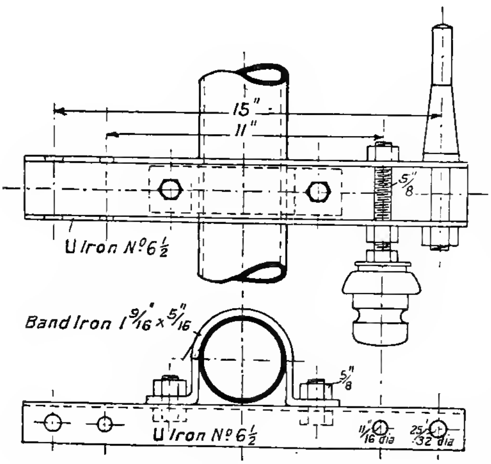


Fig. 261.

After the wire has been raised it is fixed to the first standard by means of a conical or riveted coupling, and the straining up of the lines and fixing them to the insulators can then be carried out as previously described.

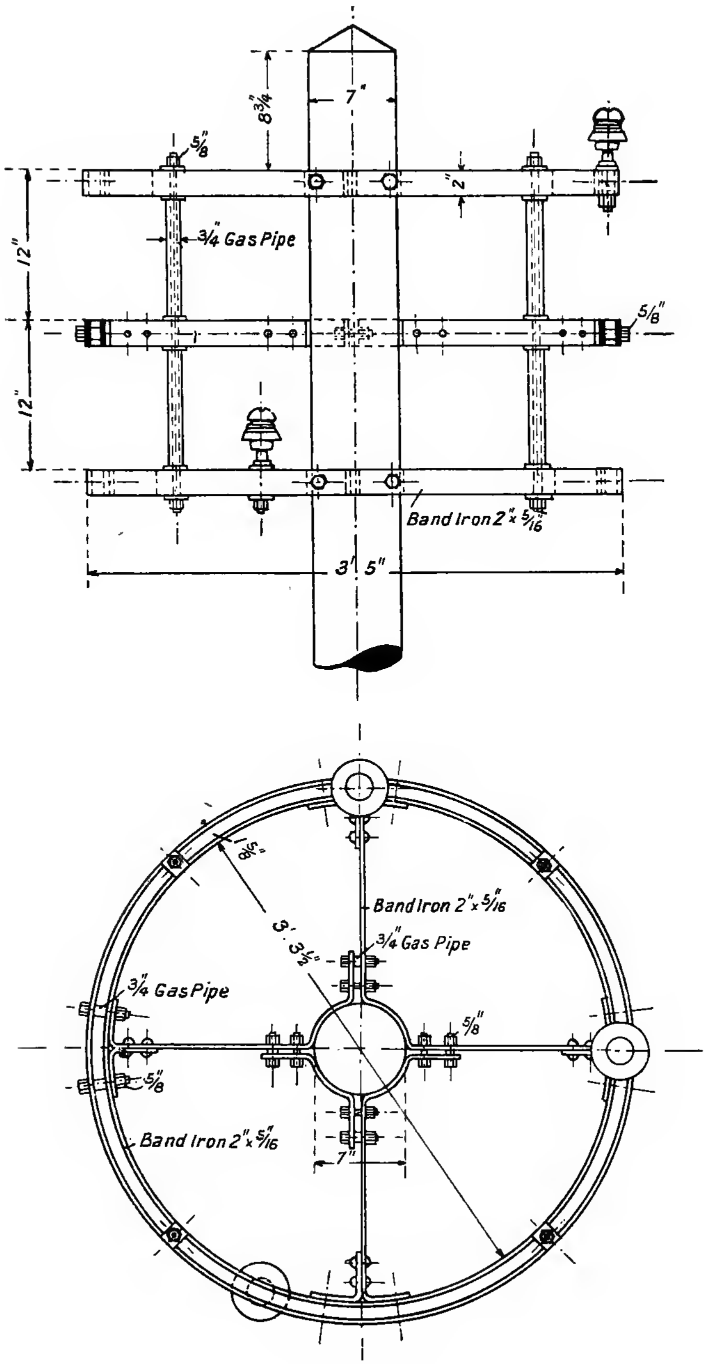

7"
8¾"
5/8"
2"
12"
12"
¾" Gas Pipe
5/8"
Band Iron 2" x 5/16"
3' 5"
1 5/8"
Band Iron 2" x 5/16"
¾" Gas Pipe
3' 3½"
¾" Gas Pipe
5/8"
5/8"
Band Iron 2" x 5/16"
7"

Fig. 262.

Distributing Points: Corner Points.

At those points in a local distributing network at which a number of wires branch off in various directions special precautions have to be taken in order to attain a neat appearance. For this purpose distributing rings are sometimes employed consisting of a pair of concentric flat iron rings as shown in Fig. 262. The insulator pins are clamped in the space between the two rings and can be arranged at any point of the circle. If fuses are to be introduced at the distributing point the arrangement shown in Fig. 263, due to Weckmar, is very convenient. The fuse can be replaced without making the line dead. For this purpose the fuse is carried in a holder with knife contacts fitting into spring clips under an ebonite cover.

If the insulator is provided with two grooves the incoming and outgoing wires can both be fastened to a single insulator and the fuse inserted between them.

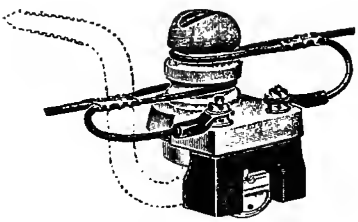


Fig. 263.

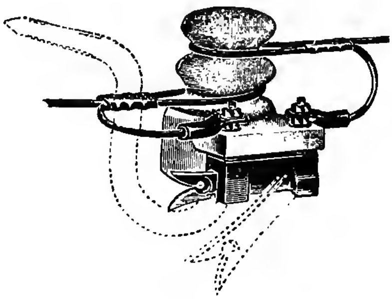


Fig. 264.

The same construction can be used for introducing a section switch as shown in Fig. 264. The switch is opened by a pull exerted on the slot at one side.

Whatever arrangement is adopted, however, the control and replacement of fuses when mounted on the masts is objectionable, especially when a fuse has to be replaced quickly on a dark and stormy winter's night. The delay is the greater because it is work which can only safely be left to experienced men. The minimum use of fuses on local overhead distributing networks should, therefore, be aimed at, but in the larger networks their introduction at certain points is unavoidable. In these cases it is a great improvement if the fuses are fixed in switch-boxes conveniently placed, instead of on the masts. The additional cost for the extra lead and return wires is small compared with the total cost of the installation. The switch-boxes then also serve as convenient places for resistance and current measurements in the various circuits.

The overhead structure at distributing and corner points should be specially carefully carried out, as they are usually prominent. Cross-arms placed one above the other should not be used unless they can be set exactly at right angles. In other cases distributing rings are preferable.

Leading-in Wires.

The point at which connection is made between the overhead line and the house wiring requires careful treatment in order to avoid the possibility of water draining in and to maintain good insulation.

The simplest arrangement consists in passing ebonite tubes through the wall and providing them on the outside with inverted funnel or bell mouth-pieces (see

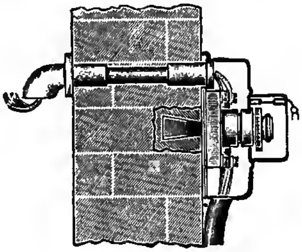


Fig. 265.

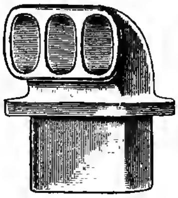


Fig. 266.

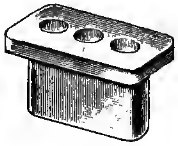


Fig. 267.

Fig. 265). For small wires twin or triple mouth-pieces in porcelain opening into a tube are sometimes used. A good arrangement is that shown in Fig. 266. This is of porcelain and has a projecting flange for bedding against the wall and large enough to cover up the ragged edges of the hole in the wall. A corresponding flanged pipe (Fig. 267) is pushed into the hole from the inside.

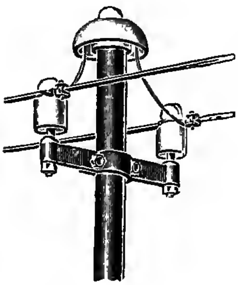


Fig. 268.

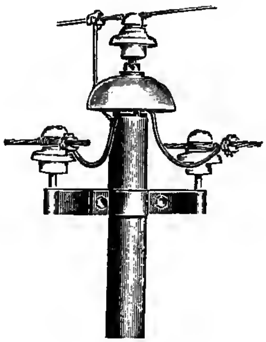


Fig. 269.

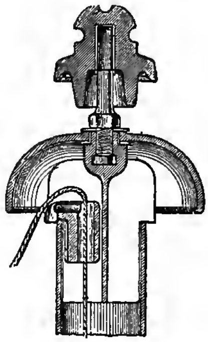


Fig. 270.

Houses carrying a tubular roof standard or wall arm can be conveniently supplied by wires running through the inside of the pipe. An upright pipe is fitted with a leading-in cover of porcelain as shown in Fig. 268. This consists of three parts—a porcelain bush, a porcelain star-piece to keep the wires separated, and a porcelain cap to keep out the rain. Figs. 269 and 270 show the same thing when provided with an additional insulator at the top of the leading-in arrangement. The additional insulator can be replaced by an earth wire terminal or a lightning conductor point if required. Another modification is shown

in Figs. 271 to 273. The special point about this type is that the underpart of the inlet is provided with lugs to which the wires can be tied with binding wire and so made more secure against damage by storms.

If leading-in wires of small section have to be carried through narrow pipes the porcelain fitting shown in Figs. 274, 275, and 276 is suitable. This is made in

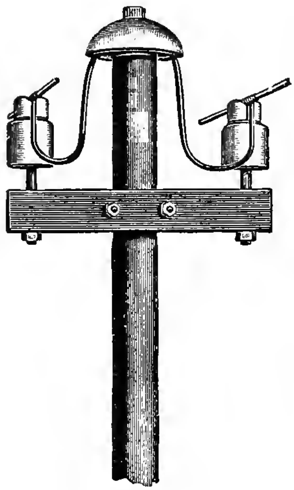


Fig. 271.

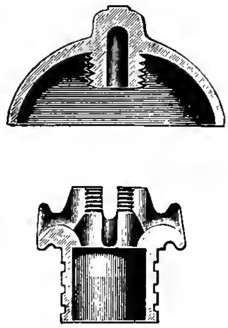


Fig. 272.

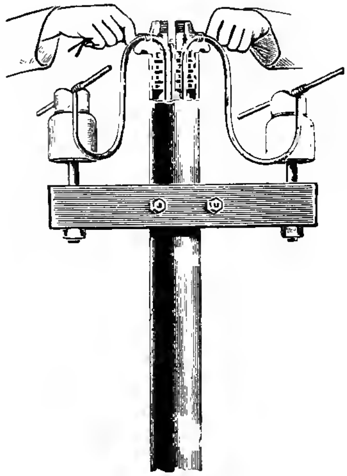


Fig. 273.

two pieces, and the upper one is fixed over the lower one, after the wires have been passed through, by means of wire pins.

Wires can be led into horizontal tubular wall brackets in the ways shown in Fig. 277 and Fig. 278. In the former the end is provided with a two or three-way inverted funnel cemented in, and in the latter the wires are carried through holes in the underside of the pipe, which are protected with insulating bushes.

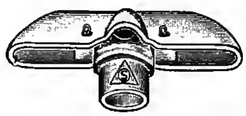


Fig. 274.

Fig. 275.

Fig. 276.

When a large number of wires have to be led in or out, as, for instance, in the case of a distributing point where the fuses are mounted on a separate switchboard, the standard can better be made in the form of a double pipe to give sufficient room, or, if the single pipe is of sufficient size, the leading-in arrangement shown in Fig. 279 can be used.

When the same thing has to be done on a wall surface a separate standard carrying the various insulators is sometimes fixed to the wall as shown in Fig. 280, which shows the connecting point between a transformer sub-station and the overhead line.

Branch and Junction Points and House Service Connections.

Soft copper cannot be used for overhead lines because of its low breaking stress and elastic limit. On the other hand, soldered joints on hard drawn or

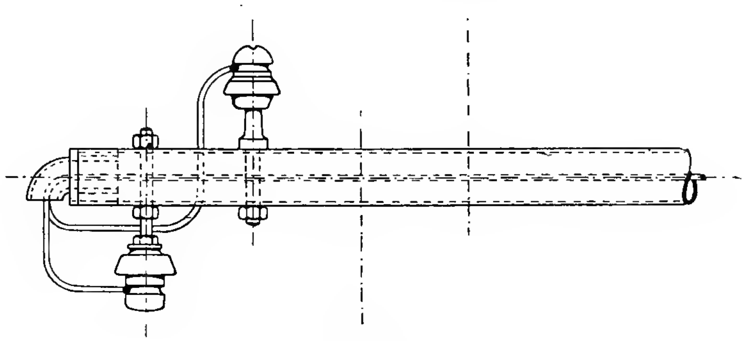


Fig. 277.

medium copper weaken the wire and are, therefore, not permissible ; consequently the joints at distributing points and for branch lines are generally made by means

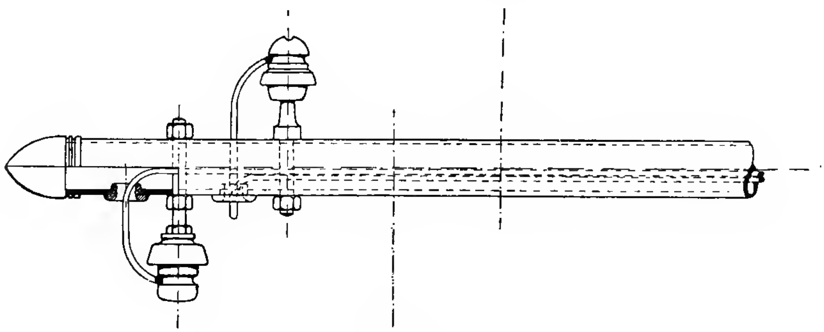


Fig. 278.

of terminals. These also cheapen the jointing process. Examples of the terminals used are shown in Figs. 281—284.

The connecting wires should be kept as straight as possible both in the vertical and horizontal planes (see Figs. 277 and 278), and all corners should either be sharp and square or neatly and regularly curved. When leading wires into fittings, etc., spirals, much employed by some wiremen, should be avoided, as they soon lose their shape and look very untidy, besides wasting wire.

All unearthed leading-in wires must be kept out of reach.

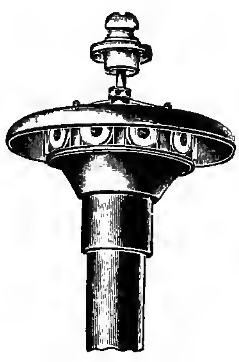


Fig. 279.

When carrying out the house connections the wires crossing the roads should be kept horizontal, as far as possible, by choosing houses of similar height on both sides of the street. Also as few crossings as possible should be used and these

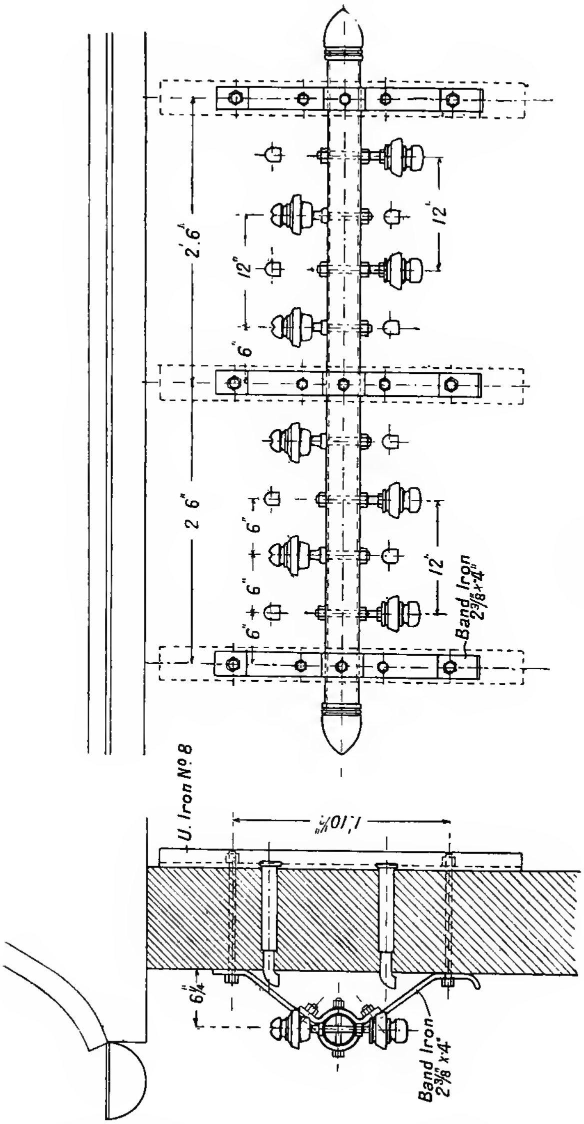


Fig. 280.

should be at right angles to the road and to the lines. For instance, if three houses like *a*, *b*, and *c* (Fig. 285) are to be supplied from one distributing point it is quite unnecessary to run three sets of wires across the road as shown. A single crossing and a continuation wire as shown at *d*, *e*, *f* are sufficient.

The wires must be kept at least 16 feet above the roadway in order to avoid interference with traffic (in many localities 20 feet is insisted upon).

As has been explained above, the fusing of house connections at the distributing point is objectionable and troublesome. The service wires need not, however, be kept of the same section as the feeders. The smallest allowable copper section for low-tension wire is ·01 square inch (rules of the V. D. E.), and this can carry a maximum current of 31 amperes when used inside buildings. When used overhead in the open the only limit to the current is that which causes a dangerous temperature rise (dangerous either to surrounding objects or to the wire itself). It is clear, then, that even the smallest section can carry such heavy currents in case of short circuits that damage to the line is unlikely.

In many country districts on the Continent plugs for supplying current to portable motors for threshing machines, wood-cutting machines, etc., are plentifully provided. These should be distributed so as to allow the motor (generally

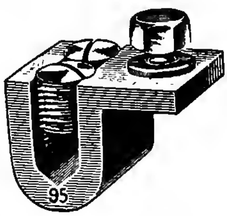


Fig. 281.

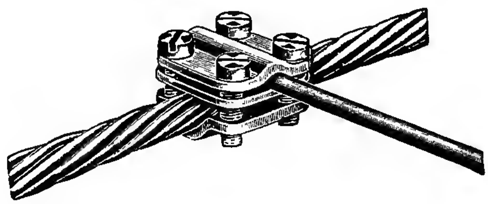


Fig. 282.

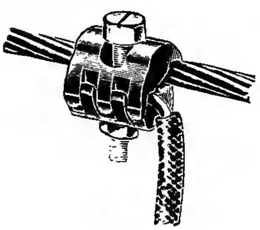


Fig. 283.

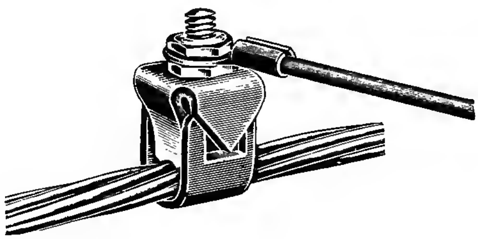


Fig. 284.

fitted with a cable drum and 80 to 100 yards of cable) to be used in practically any position. It is preferable to increase the number of sockets for plugs rather than to extend the easily damaged cable unduly.

The plug contacts should be strongly and amply designed and so arranged that the plug can only be inserted the right way round.

Short circuits have often occurred through careless handling of the flexible cable or heavy overloading of the motor, so that it is advisable to fit fuses in front of the plug and in such a way that they can be replaced by unskilled workmen.

When these plug sockets are to be mounted on wooden poles the attachment flange must be suitably curved. For wall plugs the flange is straight. The leads down to the socket should be run in piping as shown in Fig. 286. The plug and socket shown here is not provided with fuses. These should be arranged in a closed iron case above the plug socket.

Street Lighting.

In most districts the street lighting is carried out with the majority of the lamps only alight till midnight and all-night lamps are only placed at street corners and other important points. If each lamp is arranged with its own switch it can, of course, be used at will either as a half-night lamp or as an all-night one. Although this gives the simplest circuit arrangements and the lowest first cost it is seldom used because it nullifies one of the chief advantages of electric street lighting, viz., the power to switch on all the lamps from the one central station.

The two chief groups—half-night and all-night lamps—can be sub-divided into smaller groups of, say, not more than twenty lamps each. For this two additional wires would have to be run along the poles for each kind of lamp, or four additional wires in all. This is the best arrangement, as it enables the lamps to be entirely disconnected from the supply when switching off, but it is too expensive on extensive schemes.

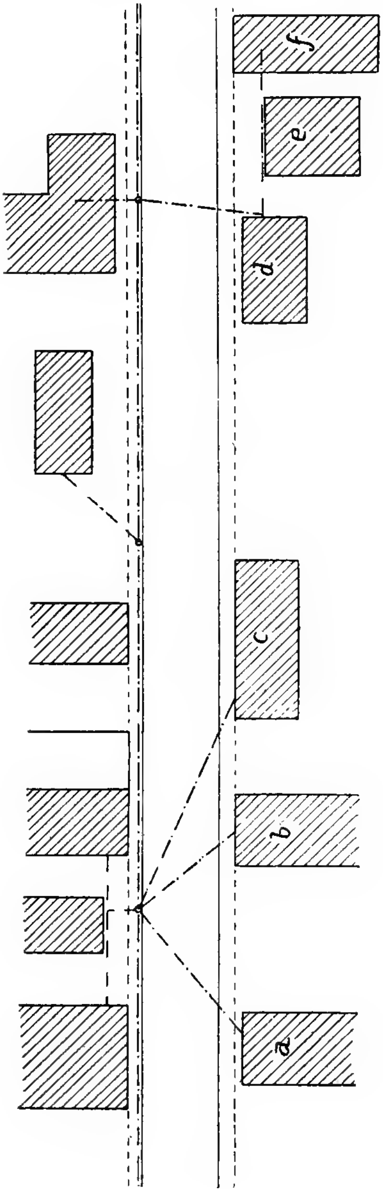


Fig. 285.

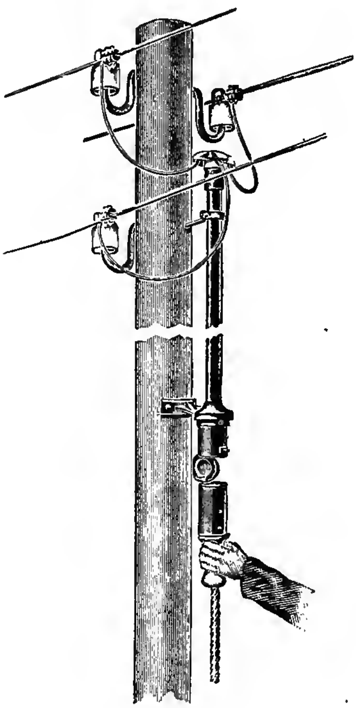


Fig. 286.

A cheaper arrangement is attained by using a single wire as the common return for both the half-night and the all-night groups (Fig. 287, top). In this

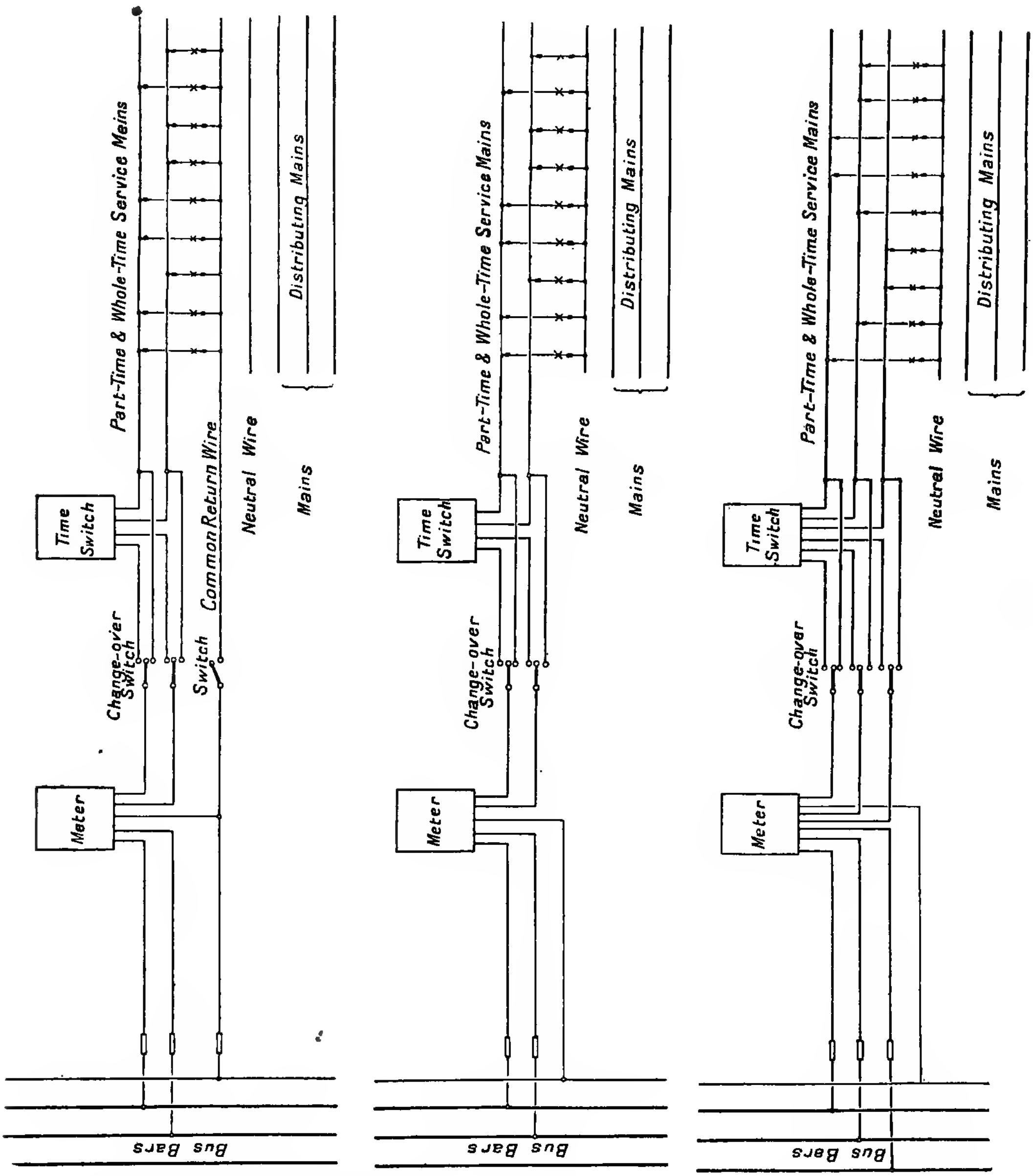


Fig. 287.

arrangement also the lamps will be dead on both poles during the daytime if the time switches used are double-pole ones. Single-pole time switches are generally provided with a hand switch so that both lines can be disconnected from them when repairs are proceeding (Fig. 287).

In the case of three-phase supplies without neutral wire the three distributing mains and the three lamp wires should be symmetrically arranged on the poles either in groups of two and four wires or in three groups of two wires.

If a fourth (or neutral) wire is provided this should be placed by itself at the pinnacle of the pole.

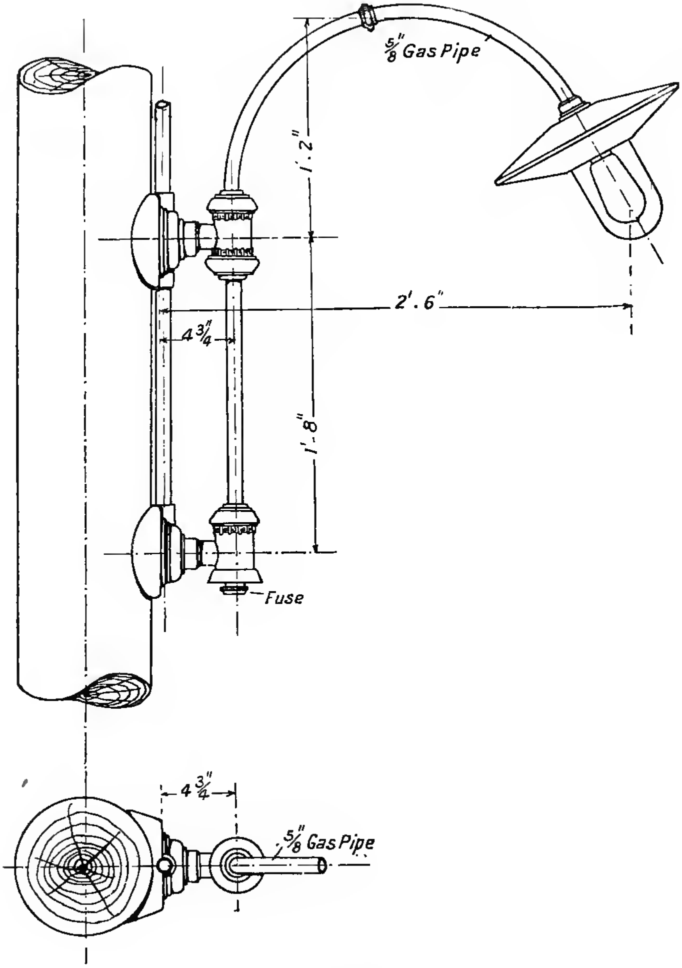


Fig. 288.

In order to reduce the cost still further it is common to connect each group of lamps between one switching wire and one of the distributing mains (Fig. 287, middle). In this way each street with part-time and whole-time lamps only requires two additional wires. The lamps, however, are alive even when switched off. Any further group of lamps will require one extra wire as shown in Fig. 287 (bottom).

In all these cases the switching is best carried out by automatic time switches,

which are now obtainable for the purpose, and which can be set to operate at any desired time. Some of these are provided with an astronomic adjustment which automatically varies the time of switching in or out by a few minutes every day in accordance with the variation in the times of sunrise or sunset.

Time switches ensure the switching on and off of lamp at definite predetermined times, but sometimes it becomes necessary to be able to switch on or off at other times owing to fire, floods or similar causes. This can be accom-

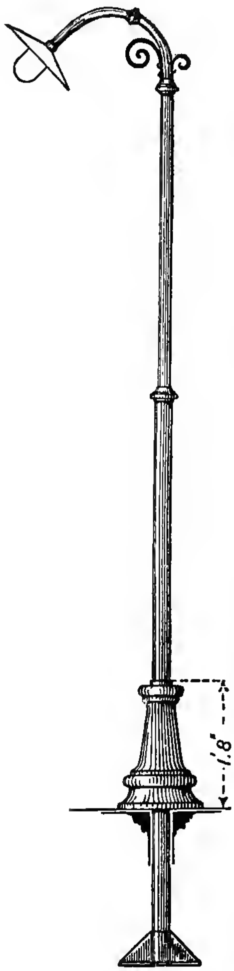


Fig. 289.

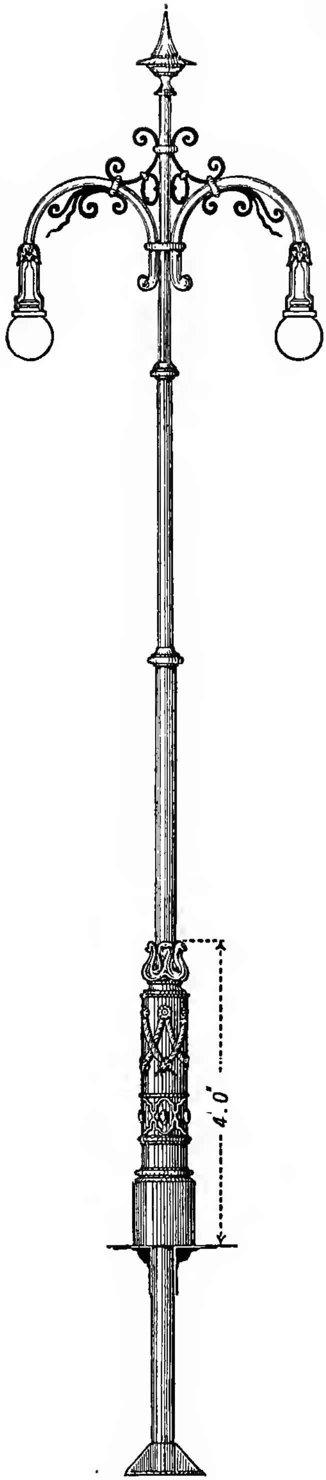


Fig. 290.

plished if hand-operated switches are introduced as shown in Fig. 287. These switches are also useful in case the time switch is out of order.

The separate lamp circuits are provided with fuses at the switching stations.

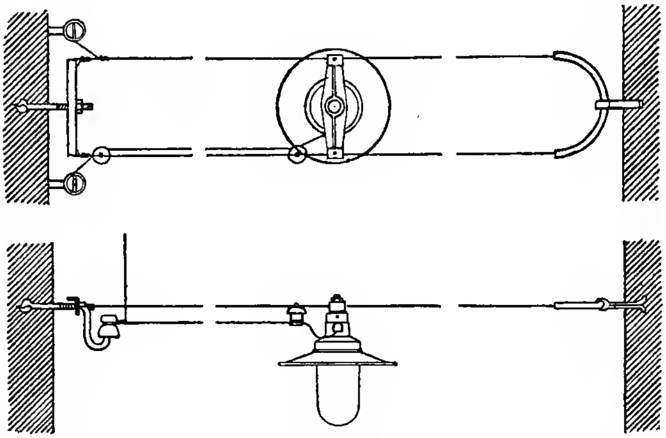


Fig. 291.

Besides these main fuses it is advisable to give each lamp a fuse at least on one pole, so that when a fault occurs the blowing of these individual fuses shall indicate the faulty point quickly. The fuses should be placed as close to the distributing

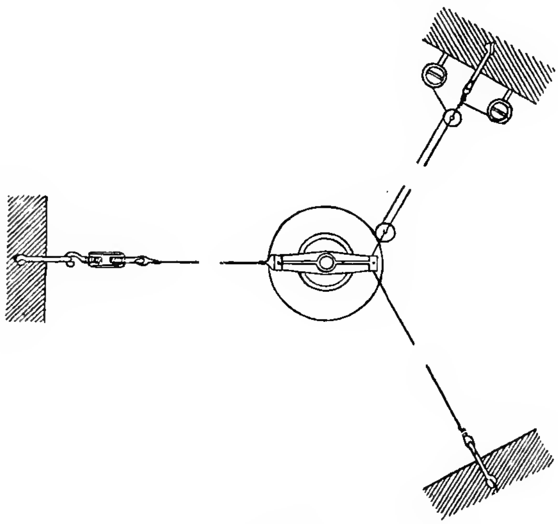


Fig. 292.

main as possible. Sometimes the fuse is inserted close to the lamp (Fig. 288), but it then only protects the lamp itself and not much of the lead to it. A better arrangement is to add a somewhat stronger fuse at the junction of the lamp lead with the distributing main so that in case of a lamp fault the lamp fuse

which is easily replaced on the spot, blows first, but, at the same time, the lamp lead is also protected.

The leads to the individual street lamps should be run in steel conduit carried down the mast or down the wall (Fig. 236).

If, owing to the use of roof standards, it is necessary to carry the lamp leads down the standards and through the interior of a house the wiring must be such that no unauthorised current can be tapped off. For this purpose the wire should be run in tubing either without joints or with joints which can be lead sealed. The lamp leads should not be run, exposed, down masts or house walls, as they are too liable to be damaged during repair work. Lamps can be fixed either to masts or houses along the roads. They are generally of 32 or 50 candle power, and are placed from 40 to 100 yards apart and, as far as possible, alternately on each side of the street. The lamps can be mounted on wall brackets (Fig. 288) or singly or in pairs on poles (Figs. 289 and 290), and the fittings used vary from the simplest to the most ornamental. The best light distribution is obtained by hanging the lamp over the centre of the street at a height of about 5 yards. This can be accomplished in a number of ways. Figs. 291 and 292 show two such suspensions. If the system works with one pole earthed the uninsulated supporting wire can act as one supply lead. If the second suspension wire is to act as the second supply lead a strain insulator must be inserted at one point (Fig. 293).

The arrangement of Fig. 292 is

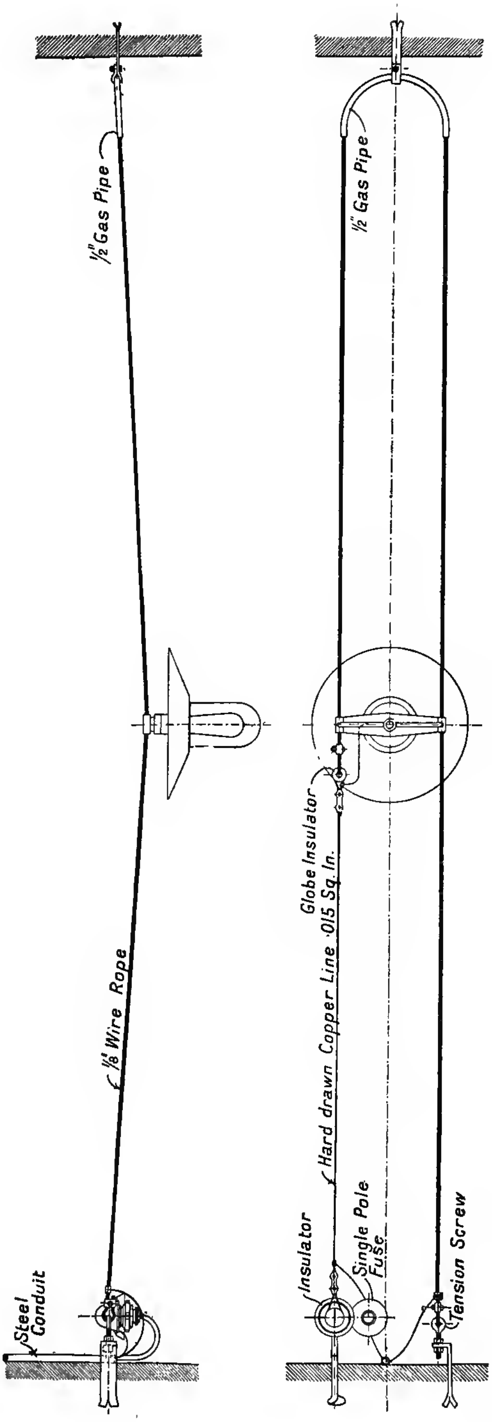


Fig. 293.

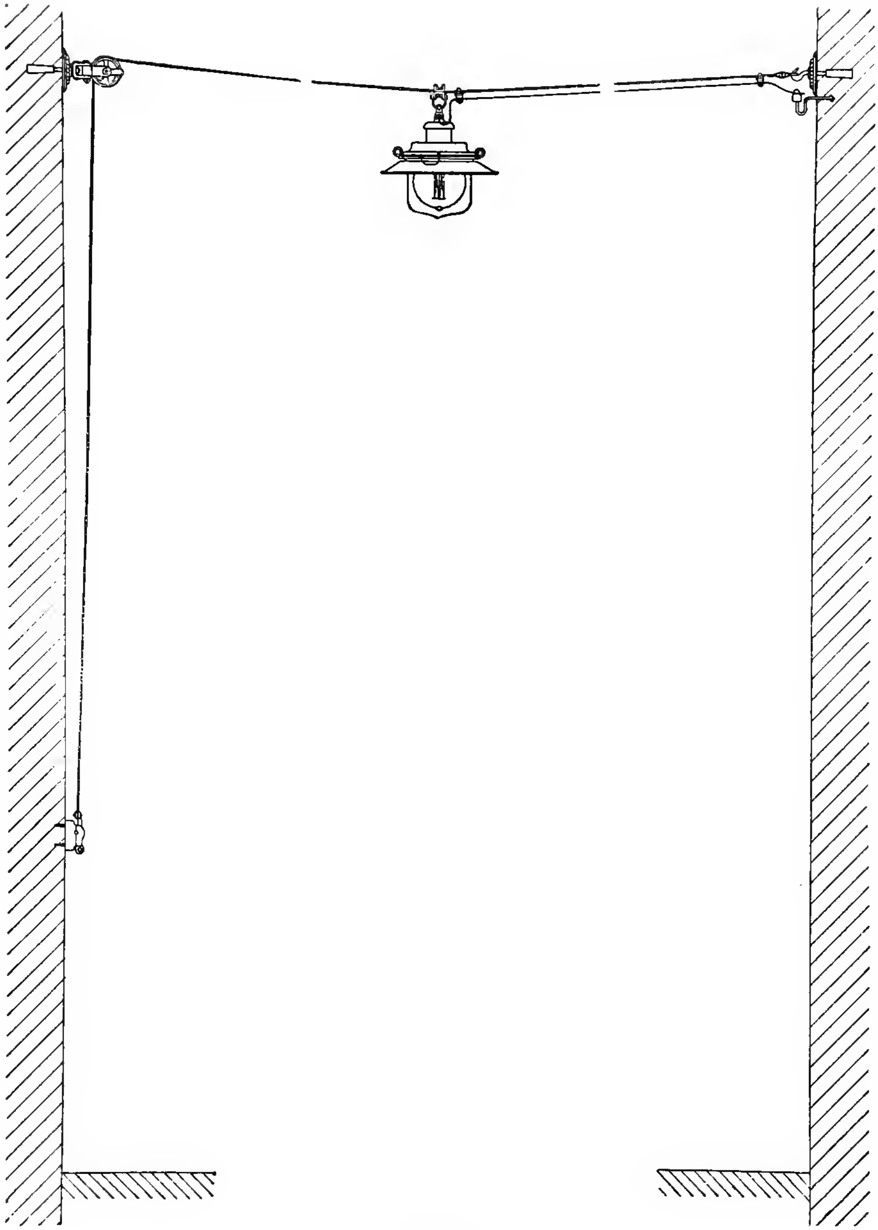


Fig. 294.

adopted when the lamp has to be placed at a spot where two houses do not face one another. In this case a ladder is needed when attending to the lamp. This inconvenience can be avoided if the lamp is arranged for lowering.

Fig. 294 shows a lowering gear due to C. A. Schäfer, of Hanover. The simple lock fitted on this is shown in Figs. 295 and 296. No ratchet is used with this

type, as the lowering is done by means of a rope carried by the attendant and hooked into the lock as shown.

Cost of Local Distributing Systems.

Local distribution schemes carried out and run by a private company only become practicable when some reasonable return on the capital expended is likely to be received. In such cases appearance is naturally little considered. The wish of every community to keep its roads and squares free from overhead wires,

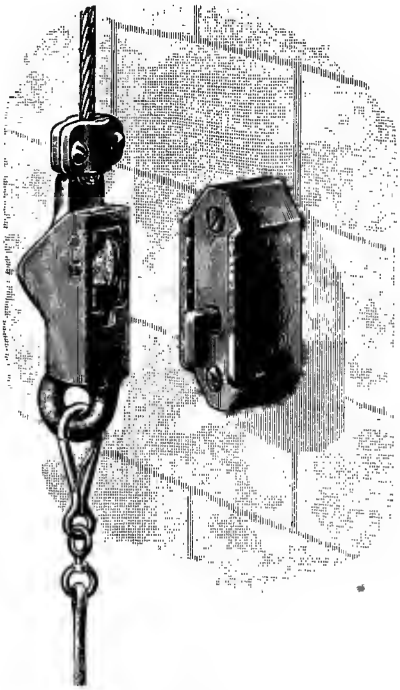


Fig. 295.

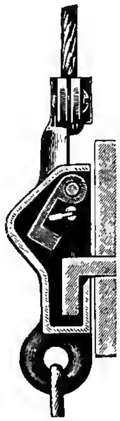


Fig. 296.

or at least to allow only pleasing structures and those of the best workmanship to be erected, often compels them to take up the matter themselves. A public authority is able to borrow money on more favourable terms than a private firm. Also with public ownership, where all the inhabitants reap the benefit of the concern, it is not so important to ensure the payment of a dividend in its earlier years. A private company cannot generally afford to use its net profits, after paying a reasonable dividend, to reduce the price of the current, because of possible losses in other ventures. Any profits which a public authority makes, on the other hand, can be used for municipal purposes even if they are not returned to the community directly in the form of lower charges for current.

A private undertaker, however, is likely to push the business more quickly

than a public authority, and will be ready to deal with large consumers earlier. It may, therefore, be advantageous in some cases for the public authority, after

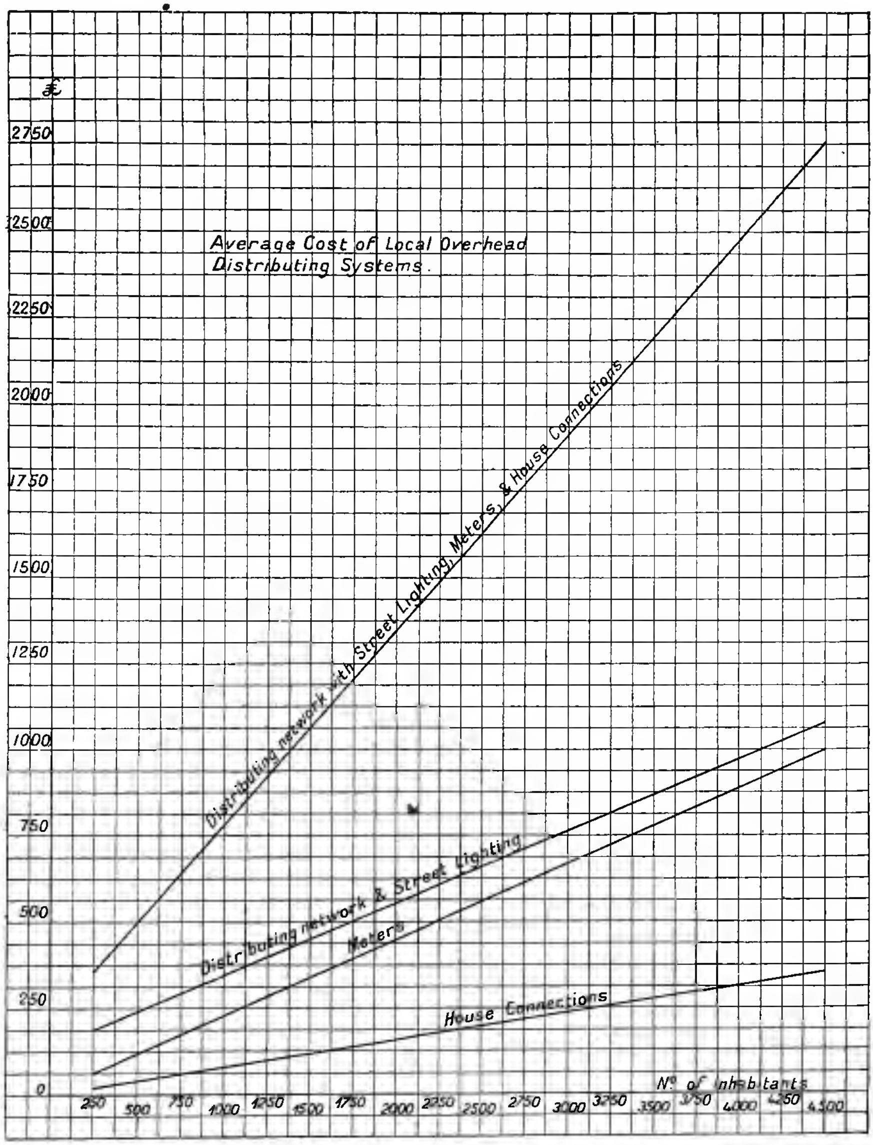


Fig. 297.

carrying out the installation, to hand it over to a private company to work, for some years at least.

Since the cost of a local distribution scheme depends on circumstances

which cannot be reduced to a uniform and generally applicable basis, it is only possible to give approximate average values as a guide in estimating.

Such values obtained from over 100 estimates are collected in the curves of Fig. 297. The price of copper has been taken as £85 per ton. The cost of house connections and meters has been based on the assumption that every two inhabitants will require one incandescent lamp and that each service will supply five lamps. The allowance for street lamps has been determined from actual town plans.

25. AGREEMENTS WITH CONTRACTORS.

Often the work of mast carriage and erection, and in some cases also the running of the wires, is handed over to contractors who make a speciality of it.

In order to avoid subsequent misunderstandings and disputes it is essential to draw up a detailed specification and agreement giving full particulars as to the commencement, progress and end of the work, method of carrying out the work, taking over, guarantees, penalties and conditions of payment. In order that this agreement may have general application it is usual to add a schedule of prices for the various separate items and giving details as to quality and type of material.

A model agreement for such a purpose is given below :—

Agreement.

Between Messrs. (hereinafter called the " Undertakers ") and (hereinafter called the " Electrical Company ").

§ 1. *General.*

The Undertakers agree to construct the overhead electrical supply system in accordance with the drawings, instructions, and schedule of prices attached to this Agreement.

The Electrical Company will supply the Undertakers, free of charge, with complete drawings, on which all necessary information will be given. Deviations from the drawings are only to be carried out on written instructions. Deviation from the drawings without such instructions will be made at the Undertakers' risk. Any additional material involved by such alterations may be deducted for by the Electrical Company from the Undertakers' account or the alterations may be put right at the Undertakers' expense.

The Electrical Company shall have the right to change the order of the work during its progress, and the Undertakers shall not make any additional charge, provided that they are able to keep their staff employed. If this is not the case, suitable compensation is to be determined and credited to them.

§ 2. *Surveying the Route of the Line.*

The positions of the masts and other important points on the line will be fixed by the Electrical Company which will also undertake to obtain all wayleaves and other necessary permits from the landowners and local authorities. The Undertakers are to check the positions marked on the drawings before commencing work, and after that they are to be held fully responsible for the correct placing of the masts, etc. They may demand copies of the permits obtained by the Electrical Company from the various owners and of the drawings submitted to the local authorities.

The mast positions will be marked by the Electrical Company with particulars

as to type, height, and foundations. The general arrangement drawing will give particulars as to cross-arms, distance between wires, cross-section of the wires, guard nets, mast switches, earth wires, etc. The numbers of the masts on the drawing will correspond with those marked along the route.

In the case of the local distributing network the masts and other supporting points will be indicated on sketches.

§ 3. *Material.*

All material required for the erection of the line, unless otherwise stated, will be supplied by the Electrical Company and will be available either at a stores within the district covered or will be delivered at the nearest railway station.

The Undertakers shall, as soon as possible after receiving the contract, supply to the Electrical Company a schedule of all material required to comply with the drawings and shall send for the material as shown on this schedule.

Masts must be called for in truck-loads, and if a whole truck-load is not used in any particular case the Undertakers must bear the difference in freight involved. The Undertakers are responsible for the correct delivery of the masts as to time and place. Any delays produced through mistakes in these points are to be made up.

The Undertakers must certify for all goods received by them. Invoices will be supplied for all goods sent by rail.

Any complaints as to quality or quantity must be notified to the stores department at once, and, if dealing with a case of rail delivery, within twenty-four hours. Later notifications cannot be considered.

After leaving the stores all goods are carried at the Undertakers' risk, and they will also be responsible for charges resulting for delay in emptying trucks. Excess material, so far as it is in good condition, will. on written notification, be taken back by the Electrical Company and allowed for. If more material has been drawn from the stores than the drawings show to be necessary, the excess may be deducted for from the Undertakers' account.

§ 4. *Commencement and Progress of the Work.*

The work is to be commenced within fourteen days of the signing of the contract, and is to be proceeded with at the rate of   yards a day. If the Undertakers are late in completing the work, a deduction of 1 per cent. on the contract price will be made for each completed week's delay, without any definite damage to the Electrical Company having to be proved. If the agreed date for completion is exceeded by four weeks the Electrical Company may hold the Undertakers responsible for all loss resulting from the delay. If the Undertakers do not commence work at the date agreed upon, the Electrical Company is at liberty, without reimbursing the Undertakers for any expenses they may have been put to, to take the work in hand themselves or to let it to a third party.

The Undertakers may refuse to commence work if more than 3 per cent. of the necessary permits are not yet in their hands. If, in spite of these omissions, the Electrical Company requires the work to proceed, the Undertakers may claim for all extra expense involved.

Applications for extensions of time may only be made by the Undertakers if there has been delay in supplying them with material, or if local authorities have stopped the work, or if changes in the route have caused delays. The permission for extension of time must be received in writing.

§ 5. *Contractors' Staff and their Supervision.*

The Undertakers are to carry out the work with their own staff. They may only sub-let with the express permission of the Electrical Company. Supervision of the work, if not done by themselves personally, must be carried out by a responsible person whose name shall be handed in to the Electrical Company.

On the part of the Electrical Company a clerk of the works will be in charge, and his requirements must be exactly complied with by the Undertakers. Grievances, suggested improvements, or alterations are to be brought before the Electrical Company in writing, and the reply in connection with them must be received in writing.

§ 6. *Standard of Work.*

The work is to be carried out in accordance with the standard regulations of the and any special rules laid down by the Electrical Company. The Undertakers further agree to comply with any additional instructions issued by the Electrical Company during the progress of the work. Any modifications necessitated by non-compliance with the rules are to be carried out immediately on written notification being given to the Undertakers at their own expense. Otherwise the Electrical Company may undertake the work or hand it over to a third party and charge the Undertakers with the cost.

§ 7. *Tools and Appliances.*

The Undertakers must supply all necessary tools and appliances for the work and for the transport of the materials without extra charge. They are also to provide the necessary materials for mast foundations such as stone, gravel, sand, cement, etc. The Electrical Company is to have the right to test any materials at any time and to reject any not up to the standard quality.

§ 8. *Work lying outside the Contract.*

Work not included in this contract and for which no price has been specified must not be carried out without written permission. If this rule is ignored the Electrical Company may cause such work to be dismantled at the cost and risk of the Undertakers. No payments will be made to the Undertakers for such unauthorised work.

§ 9. *Responsibility of the Undertakers.*

The Undertakers take full responsibility for compliance with all laws and bye-laws dealing with the safety and insurance of workmen or other persons. They guarantee the Electrical Company against all charges for damage due to their negligence.

An exception is to be made in the case of damage to cultivated land as a result of carrying the line across it, such damage being made good by the Electrical Company.

§ 10. *Guarantees.*

The Undertakers agree to employ only the best material, and guarantee the quality of the workmanship for a period of one year. All expenses due to defective material or workmanship during that period are to be made good at their expense within fourteen days of written notice being given. Otherwise the Electrical Company may undertake the work and charge the Undertakers for it.

§ 11. *Taking over the Work.*

The Undertakers are to notify the Electrical Company in writing of the completion of the work. Within fourteen days of this notification a joint examination and inspection of the whole work shall be made, and the material used shall be checked over. The number of parts used shall be counted and the length of wire shall be determined by measuring the straight distance between the masts. An allowance in length for the sag and waste and in the number of insulators through breakage shall be made amounting to 3 per cent. If this inspection should show that the work does not comply with the specification in any point, the Undertakers shall be allowed a period of   days to put the matter right. If at the end of this period the work is still not in order, the Electrical Company shall be free to undertake the work themselves or to engage others to do it and to charge the Undertakers with the expenses thus incurred. The Undertakers shall be responsible for the whole of the work until it has been taken over by the Electrical Company.

§ 12. *Penalties and Payment.*

The Undertakers agree to pay in the sum of £   to cover calls upon them in the way of penalties, etc.

Payment will be made within four weeks of the taking over of the work provided the account is sent in within fourteen days of that date. The Undertakers, during the carrying out of the work, are entitled to demand payments on account up to 90 per cent. of the value of the work completed at the time. Proof of the value of work completed must be produced by the Undertakers.

§ 13. *Arbitration.*

In the case of any dispute or question with regard to this contract arising, it is to be submitted to arbitration. Each party may propose an arbitrator within fourteen days, and these will then, within one month, select a referee. If the arbitrators are unable to agree as to a referee the latter is to be selected by   . If either party fails to select an arbitrator within the time, the other party shall be free to select the second arbitrator as well within another period of fourteen days.

The arbitrators and referee after hearing both sides are to hand in a written report within one month, and this shall be binding on both parties. This report shall also contain provisions for the payment of the cost of the arbitration.

§ 14. *Signatures.*

The contract is to be prepared in duplicate and each party is to sign both copies and to retain one of them.

Special Regulations for the carrying out of Overhead Line Installations.

The undertakers must take every precaution so as to reduce damage to property to a minimum. Damage due to faulty workmanship or malice must be made good by the undertakers.

When excavation work has to be carried out on agricultural land the surface soil must be separated and used again for covering the spot when the work is

completed. Turf must be replaced where necessary. The ground surface must be put back into its original state within eight days. Any superfluous material is to be removed within four days.

The foundations used must be such that the ground pressure does not normally exceed lbs. per square inch. If the undertakers consider that the stratum of soil met with at the given depth is unable to support that pressure they must notify the clerk of the works at once verbally and the electrical company in writing. The electrical company must then decide the matter. Any additional weight of concrete that may be required shall be credited to the undertakers at the rate agreed upon.

The masts must be transported and unloaded carefully. Bent or damaged parts must be replaced at the undertakers' expense. The erection must not be delayed for want of lifting tackle, scaffolding, etc.

Masts in straight stretches must be set vertically so as to cover one another exactly in the line of sight. Masts at corner points are to be given a set or rake according to instructions from the electrical company.

All iron parts must be delivered ready painted. If several coats have been specified these must be of sufficiently different shades to make the difference easily noticeable. The colour of the last coat is to be specified by the electrical company.

The undertakers may use any suitable material obtained in the course of the excavation work in making the concrete. The sand used must be sharp. Sand and gravel must contain no loamy or clayey admixture. If necessary the materials must be washed before use. Broken stone must be reduced to $2\frac{3}{4}$ inches diameter at most. Soft stone must not be used. The water used in making the concrete must be quite clean and free from scum. The concrete, of the consistency of moist earth, is to be put in in layers 6 or 8 inches deep and well punned. If either a frost occurs or there is great heat the newly-laid concrete must be well covered up.

The earthing of the masts, etc., must be specially carefully carried out to the instructions of the electrical company.

Barbed wire protection is to be fitted to the masts after the wires have been erected. Danger notices are to be attached to the masts after they have received their last coat of paint.

Aluminium wire must not be drawn along the ground, and copper wire must not be drawn over stony land or roads. Faults in the wire, if discovered during erection, must be cut out and notified to the electrical company at once.

The wires are to be tested with a dynamometer for tension and sag in accordance with the tables supplied by the electrical company.

In straight stretches butt joints covered by thin split copper tubing only are to be used.

Any openings which have had to be made in roofs are to be covered during rain and after working hours. Bad and unreliable roof structures must be suitably strengthened.

The undertakers are to instruct their employees to take special care in connection with roof work, so that the owners are disturbed as little as possible.

The staff employed on local distribution systems is to be carefully chosen, and the electrical company shall have the right to discharge men whose conduct is open to censure.

SCHEDULE OF PRICES FOR HIGH-TENSION TRANSMISSION LINE WORK.

	s.	d.
1. Carriage (from the stores or railway siding) and erection of wooden poles, excavating holes for them 6 feet 6 inches deep, punning in the soil again, leaving the surface in its original state, and removing all superfluous material:		
Up to 36 feet long, per pole	5	3
,, 39 ,, ,,	6	0
,, 43 ,, ,,	6	6
,, 46 ,, ,,	7	3
2. Wedging the poles with two layers of broken stone (including the supply of 7 cubic feet of hard broken stone):		
Extra per pole	2	6
3. Carriage and erection of struts, excavating hole 5 feet deep, fastening strut to pole with ¾ inch bolt, setting the strut in position, supplying and setting a base plate of stone or hard wood, filling in and making good:		
Per strut	7	0
4. Carriage and erection of double masts of A form as under (1), fitting the two poles together, supplying two old railway sleepers for the foot (8 feet 6 inches long, 5½ inches deep, 9 inches wide) and two beams impregnated with creosote (about 36 × 5 × 9 inches) for the central cross-piece and supplying five ¾ inch bolts:		
36 feet long	25	6
39 ,,	27	0
43 ,,	29	0
46 ,,	31	0
5. Wedging these poles as under (2)	5	0
6. Carriage and erection of mast feet of channel iron, excavating 5-foot hole as under (1):		
Per mast foot	3	6
7. Carriage and erection of wooden poles in mast feet, including wedging and supplying the wedges of hard wood impregnated with linseed oil:		
Up to 29 feet long, per pole	4	0
,, 36 ,, ,,	4	5
,, 39 ,, ,,	4	8
8. Fitting a stay of round iron rod, including excavating a 5-foot hole for an anchor plate, supplying a stretching screw and strain insulator, and making good	4	7
9. Carriage and erection of an iron mast 36 to 46 feet long:		
Up to a weight of 10 cwt., per mast	16	0
,, ,, 20 ,, ,,	24	0
,, ,, 30 ,, ,,	29	0

	s.	d.
10. Excavating for concrete foundations, per cubic yard	1	6
11. Carrying out the concrete foundation work with a concrete mixture in the ratio 1 : 3 : 6, smoothing the outer surface of the foundation block where it projects above ground, removing superfluous material and making good :		
Per cubic yard	15	6
12. Additional cost where a caisson has to be used to exclude water :		
Up to 3 feet depths, per mast	14	6
,, 5 ,, ,, ...	22	0
13. Additional cost when water has to be drawn off :		
Up to 3 feet of water	9	0
Greater depth, or rock work	14	0
14. Fitting a plain wooden pole or wooden A pole with 3 insulators on pins screwed into the wood	1	6
15. Fitting a plain wood pole or wooden A pole with a cross-arm with two insulators and with a top cap for one insulator	1	8
16. Fitting a plain wood pole or a wooden A pole with three brackets for one insulator each, a top cap to carry an earth wire and connecting the earth wire to the brackets	2	7
17. Fitting an iron mast with a cross-arm for two insulators and a top cap for one other insulator.	1	2
18. Fitting an iron strain mast with a double cross-arm with four insulators and two more insulators on a top cap	2	10
19. Fitting an iron mast for a special safety crossing for three wires .	3	6
20. Fitting an iron mast with three cross-arms for one insulator, each .	1	7
21. Fixing an insulator on its pin, including supply of the necessary hemp, red-lead, and felt washers	0	2
22. Fitting an earthing bow	1	6
23. Fitting a hoop guard	0	5
24. Fitting a safety loop	0	5
25. Providing an earth connection, including excavation to a depth of 6 feet 6 inches, sinking an earth plate, or driving in an earthing pipe, connecting it to the earth wire, connecting the earth wire to the mast, and providing a safety covering above the ground. . . .	11	0
26. Erection of a mast switch for operation from the ground, including provision of enclosing casing for the operating ropes	21	0
27. Fitting a " Danger " notice	0	2
28. Running wires ready for use, including laying out, tightening and fixing the three wires, making the joint and branch connections, assuming an average distance between masts of 120 to 170 yards :		
Wires ·0155 square inch each, per yard of single wire . . .	0	0·6
,, ·025 ,, ,, ,, .	0	0·7
,, ·039 ,, ,, ,, . .	0	0·85
,, ·055 ,, ,, ,, . .	0	0·95
,, ·078 ,, ,, ,, . .	0	1·05

	s.	d.
29. Erection ready for use of a double telephone line of bronze or steel wire up to a wire section of ·0155 square inch, making joints, branch connections and crossings:		
Per yard of double line	0	0·7
30. Erection of an earthing wire or guard wire up to ·055 square inch section, laying, tightening, and attaching to mast cap or terminals:		
Per yard run	0	0·8
31. Giving iron masts a double coat of paint, including supply of the rust-proof paint:		
Per 1 cwt. weight of mast	1	2
32. Numbering the masts:		
Per mast	0	2½

SCHEDULE OF PRICES FOR OVERHEAD LOCAL DISTRIBUTING SYSTEMS.

	s.	d.
33. Carriage and erection of wooden poles of diameters up to 7 inches (as detailed under (1)):		
Up to 30 feet long, per pole	4	6
,, 33 ,, ,, ...	4	8
,, 36 ,, ,, ...	4	11
,, 39 ,, ,, ...	5	1
,, 43 ,, ,, ...	5	5
,, 46 ,, ,, ...	5	10
34. Addition when the soil is under the water level:		
Per pole	5	0
35. Additional cost of plaster work:		
Per pole	1	6
36. Wedging in a pole with two layers of broken stone, including the supply of 7 cubic feet of hard broken stone:		
Per pole	2	0
37. Carriage and erection of strut as detailed under (3) without plaster work	6	2
38. Erection of a stay wire of round iron rod or wire rope as under (8), excluding the insertion of a strain insulator and plaster work .	3	8
39. Erection of a stay wire without earth anchoring	3	0
40. Carriage and erection of iron masts up to 40 feet long:		
Weight up to 6 cwt.	12	0
,, 10 ,, ...	14	0
,, 20 ,, ...	21	0
41. Excavation work for concrete foundations:		
Per cubic yard of excavated soil	1	6
42. Carrying out the concrete foundation work as under (11):		
Per cubic yard	14	0
43. Extra when the bottom of the foundation is under water level up to a depth of 3 feet	10	0
44. Extra for plaster work:		
Per mast	3	7

	s.	d.
45. Erection of a bracket or wall arm :		
With two fixing points	4	2
,, three ,, ...	5	0
,, four ,, ...	6	2
46. Erection of a tubular roof standard, including the necessary roof strengthening work and fitting the necessary rain-proof joint, but excluding the making good of the roof	7	6
47. Erection of a double tubular roof standard as in (46)	14	0
48. Fixing an insulator on its pin, including the supply of the necessary hemp, red-lead and felt washers	0	$1\frac{3}{4}$
49. Fixing a cross-arm with two insulators on either a wooden or iron pole	0	7
50. Ditto, with four insulators	0	10
51. Erecting a ring-shaped insulator support for distributing points on wooden or iron poles	3	2
52. Fitting an insulator by screwing into wooden pole	0	4
53. Fitting a straight pin insulator to cross-arm, etc.	0	3
54. Fitting an insulator with cement	0	8
55. Fitting a mast cap to take an earthed wire or earthing cable . .	1	2
56. Sinking an earth plate or driving in an earthing pipe, connecting it with the earthing wire and to the neutral wire, fastening the earthing wire to the mast and giving it a protecting covering above the ground	9	6
57. Erection of a single pole lightning conductor and connecting it to the earth wire or earth plate	2	2
58. Erection of an overhead fuse or section switch and connecting it with the lines	1	7
59. Running the line wire complete and ready for use, including laying out, tightening and tying in, making joints and branch connections :		
(*a*) For bare conductors of ·01 square inch section, per 100 yards .	4	2
,, ,, ·0155 ,, ,, .	4	7
,, ,, ·025 ,, ,, .	5	6
,, ,, ·039 ,, ,, .	6	0
,, ,, ·055 ,, ,, .	6	10
,, ,, ·078 ,, ,, .	7	10
,, ,, ·108 ,, ,, .	9	2
(*b*) Insulated conductors of ·01 square inch section, per 100 yards	4	7
,, ,, ·0155 ,, ,, .	5	1
,, ,, ·025 ,, ,, .	6	3
,, ,, ·039 ,, ,, .	6	10
,, ,, ·055 ,, ,, .	8	0
,, ,, ·078 ,, ,, .	9	2
,, ,, ·108 ,, ,, .	10	7
60. Making joints between bare and insulated conductors :		
Per pair	1	7
61. Provision and erection of flat safety screens of galvanised wire, consisting of three longitudinal wires and cross-wires at 1 yard intervals, erecting the necessary cross-arms, and attaching the screen to the same :		
Per yard	1	2

		s.	d.
62.	Provision and erection of box safety nets with seven longitudinal wires, otherwise as in (61):		
	Per yard	2	5
63.	Erection of a wall arm or bracket and connecting it to the overhead lines	6	6
64.	Carrying out a house service connection up to 10 yards in length, including the fixing of the insulators and the making of the joints:		
	Two wire connection	3	10
	Three ,, ...	6	2
	Four ,, ...	9	6
65.	Extra for length above 10 yards, per yard of single wire	0	1
66.	Giving two coats of rust-proof paint to a cross-arm with two insulators	0	7
67.	Ditto, with four insulators	1	1
68.	Ditto, for a simple roof standard or wall bracket	1	4
69.	Ditto, for a double roof standard	2	6

26. TOOLS AND APPLIANCES.

(a) For the Erection of High-Tension Installations.

1. 1 tool box 4 feet × 2 feet 3 inches × 2 feet 3 inches.
2. 12 screw or conical terminals for wires from $\frac{3}{8}$ to 1 inch in diameter.
3. 12 ditto for wires ·04 to ·4 inch in diameter.
4. 12 pairs of draw tongs for wires from ·04 to ·5 inch in diameter, each fitted with 1 yard of chain and a hook.
5. 10 stretching screws, each with two screws.
6. 2 bolt cutters, 2 feet long.
7. 1 dynamometer for a pull of 1 ton.
8. 1 ditto for a pull of $\frac{1}{2}$ ton.
9. 1 hack saw with six blades.
10. 4 2-lb. hammers.
11. 2 1$\frac{1}{4}$-lb. hammers.
12. 1 riveting block.
13. 4 8-inch flat chisels.
14. 4 cross-cut chisels.
15. 5 punches (various).
16. 1 adjustable square.
17. 1 thermometer.
18. 1 spirit level.
19. 1 plumb line.
20. 2 flat files with handles.
21. 2 round files with handles.
22. 3 three-square files.
23. 12 $\frac{5}{8}$-inch bolts with hooks and eyes, 16 inches long.
24. 2 shifting spanners, 10 inches.
25. 15 different spanners.
26. 1 pair of pincers.
27. 2 pairs of gas pliers.
28. 12 combination pliers.
29. 2 universal pipe grips.
30. 4 screw-drivers.
31. 1 mallet.
32. 1 hand-vice.
33. 4 wood-borers, $\frac{3}{4}$ inch.
34. 1 measuring tape, 60 feet long.
35. 4 long scales.
36. 2 complete sets of riveting tools for making riveted clamp joints.
37. 1 spoke shave.
38. 1 quart-size soldering blow-lamp.
39. 12 safety belts with tool pockets.
40. 7 pulley blocks with 25 yards of $\frac{1}{2}$ inch rope to each.

41. 8 pairs of climbing irons of 10-inch width.
42. 10 sets of rollers, each set containing two rollers for fixing on cross-arms and one roller for fixing at the top of a mast.
43. 1 hatchet.
44. 1 saw.
45. 1 axe.
46. 1 spade.
47. 1 shovel.
48. 1 vice.
49. 2 sets of V blocks for mounting cable drums on.
50. 1 turntable.
51. 1 hand-cart.
52. 1 small trolley with two wide wheels.

(*b*) For the Erection of Low-Tension Installations.

1. 1 tool box 4 feet × 2 feet 3 inches × 2 feet 3 inches.
2. 12 screw or conical terminals for wires $\frac{3}{8}$ to 1 inch in diameter.
3. 12 ditto for wires from ·04 to ·4 inch in diameter.
4. 12 pairs of draw tongs for wires from ·04 to ·5 inch in diameter.
5. 10 stretching screws, each with two screws.
6. 2 bolt cutters, 2 feet long.
7. 1 dynamometer for a pull of 12 cwt.
8. 1 ditto for a pull of 4 cwt.
9. 1 hack saw with six spare blades.
10. 4 2-lb. hammers.
11. 2 $1\frac{1}{4}$-lb. hammers.
12. 1 riveting block.
13. 4 flat chisels.
14. 4 cross-cut chisels.
15. 5 punches (various).
16. 1 adjustable square.
17. 1 thermometer.
18. 1 spirit level.
19. 1 plumb line.
20. 2 flat files with handles.
21. 4 round files with handles.
22. 3 three-square files with handles.
23. 12 $\frac{5}{8}$-inch bolts with hooks and eyes, 16 inches long.
24. 2 shifting spanners, 10 inches.
25. 15 different spanners.
26. 1 pair of pincers.
27. 2 pairs of gas pliers.
28. 12 pairs of combination pliers.
29. 2 universal pipe grips.
30. 4 screw-drivers.
31. 1 mallet.
32. 1 hand-vice.
33. 4 wood-borers, $\frac{3}{4}$ inch.
34. 1 measuring tape, 60 feet long.
35. 2 complete sets of riveting tools for making riveted clamp joints.

36. 1 hollow auger.
37. 1 spoke-shave.
38. 1 quart-size soldering blow lamp.
39. 12 safety belts with tool pockets.
40. 7 pulley blocks with pulleys 2 inches in diameter and 20 yards of rope to each
41. 8 pairs of climbing irons 10 inches wide.
42. 20 small rollers for fixing on cross-arms.
43. 1 hatchet.
44. 1 saw.
45. 1 axe.
46. 1 spade.
47. 1 shovel.
48. 3 ladders 20 to 33 feet long.
49. 1 vice.
50. 1 handcart.

27. REGULATIONS DEALING WITH THE ERECTION AND OPERATION OF OVERHEAD LINES.

(1) Board of Trade Regulations for Overhead Lines.*

Under articles 2 and 22 of the regulations prescribed by the Board under section 4 of the Electric Lighting Act, 1888 :—

Conductors.

(1) The conductors shall be hard drawn copper wire or aluminium.

(2) Hard drawn copper wire conductors shall have a breaking load of 24 tons per square inch and on breaking the elongation shall not be less than 2 per cent. in a length of 10 inches. Aluminium conductors shall have a breaking load of not less than 12 tons per square inch and on breaking the elongation shall be not less than 3 per cent. in a length of 10 inches.

(3) The minimum sag of the conductors shall be regulated to give a stress due to its weight and to wind (but excluding its elasticity) of not more than one-fifth of the breaking load, at a temperature of 22° F. Wind pressure shall be taken at 25 lbs. per square foot, and the effective area of the conductor shall be taken as ·6 of the diameter multiplied into the length.

(4) The minimum height of any part of any conductor from the ground shall not be less than 20 feet except with the consent of the Board of Trade.

(5) Conductors shall not cross any building other than a sub-station or be accessible to any person from any building or tree without the use of a ladder or other special appliance. Where the conductors are so placed that a tree, if uprooted, could come into contact with a conductor an earthed cradle enclosing them or some other precaution, approved by the Board of Trade, shall be provided to prevent all danger of any shock.

(6) Conductors shall not be carried by undertakers across the premises of a consumer except with the consent of the Board of Trade and subject to such conditions as the Board may prescribe.

Poles.

(7) The conductor shall be carried on poles either (*a*) wooden poles, or (*b*) poles or structures of iron or steel, hereinafter called steel poles.

(8) Each pole shall be clearly and permanently marked with a number.

(9) Danger notices shall be fixed on at least one pole in five and on each pole at the crossing of a road.

(10) Provision shall be made to prevent climbing by barbed wire being coiled round the pole in one or more coils of an aggregate length not less than 2 feet, the lowest coil being at least 8 feet from the ground.

(11) Where guys or stays are used they shall be securely anchored and earthed.

(12) A continuous earth wire shall be carried from pole to pole, and shall

* For a collection of the various Board of Trade regulations dealing with electrical supply, see *Electrician,* " Electrical Trades Directory."

be well connected to substantial earth plates at intervals of not more than five spans, or the ironwork on each pole shall be connected to a substantial earth plate.

Wooden Poles.

(13) The poles shall be sound winter-felled red fir, free from large knots or other defects, with the natural butts, and shall be well injected with creosote, or they shall be of a description approved by the Board of Trade.

(14) Single poles or A poles shall be used for the ordinary run of the line. Stouter poles, H poles, or built-up or strutted poles, provided, if necessary, with stays, shall be used for terminals, for intermediate anchor poles, for important differences of span, and for corner poles where there is considerable change of direction. Ordinary poles provided with stays shall be used where the direction makes a small change.

(15) Poles of ordinary lengths, unless in rock foundation, shall be set in the ground to a depth of 6 feet. The earth shall be well punned into the holes. Where necessary they shall be set in concrete.

(16) The factor of safety for the poles shall be calculated at 10 for a wind pressure of 25 lbs. per square foot, the effective area of a round pole being taken at ·6 of the mean diameter of the exposed part into the length of that part.

Steel Poles.

(17) Poles of tubular type shall be painted with oil paint not less than once every five years, and poles of lattice type not less than once every three years.

(18) Each pole shall be set in concrete.

(19) The concrete below the pole shall be dropped on to a substantial cast-iron earth plate bonded to the pole by a wire or rod.

(20) The factor of safety of the pole shall be not less than 6 taking the maximum wind pressure at 25 lbs. per square foot. In the case of lattice poles the pressure on the lee side will be taken as one half of the pressure on the windward side.

Arms.

(21) The conductors shall be carried on insulators mounted singly, or in pairs on steel channel arms, or singly upon iron brackets fastened to the poles; or, if wooden arms are used, an earthing strip or stout wire shall be fastened on the upper side of each arm.

Road Crossings.

(22) Where the line crosses over a public road, canal, or railway, the angle between the line and the direction of the road, canal, or railway at the place of crossing shall not be less than 60° and the height of the line not less than 25 feet.

(23) Where the line crosses over a public road, canal or railway, or runs parallel to it at a distance less than one and a half times the height of the highest wire from the ground, it shall be erected in a manner approved by the Board of Trade.

Where for the protection of his electric lines or works the Postmaster-General makes requirements which, in addition to protecting these lines or works, afford ample provision for securing the safety of the public, further protection need not be provided.

(24) Provision shall be made by earthing brackets or wires, or other device, to ensure that in the event of a failure of a conductor or of a pole, the line will be put to earth.

General.

(25) Galvanised iron wire used for stays, cradles, or other mechanical purpose, galvanised iron binding wire, arm bolts, nuts and washers, stay swivels, truss and brace rods and truss ties, tie and brace bolts, stay rod tighteners, and test pieces shall conform with the British standard specification for such material (British standard specification of telegraph material) so far as that specification is applicable.

(26) The work shall be carried out, so far as circumstances permit, in accordance with the Post Office Technical Instructions for the Construction of Aerial Lines.

(27) Where the line crosses, or is in proximity to, any other line or metal, precautions shall be taken by the undertakers against the possibility of a conductor coming into contact with the other wire or metal or the other wire or metal coming into contact with the line by breakage or otherwise.

(28) Every line, including its supports and all the structural parts and electrical appliances and devices belonging to or connected with the line shall be duly and efficiently supervised and maintained as regards both electrical and mechanical conditions.

(29) Every line, including its supports, will be removed on ceasing to be used for the supply of energy unless the Board of Trade are satisfied that it is to be again brought into use for such supply within a reasonable time.

(2) Regulations of the Verband Deutscher Elektrotechniker for Overhead Transmission Schemes.

§ 22. *Overhead Lines : General.*

(*a*) Unearthed overhead lines must only be run on porcelain insulators or equally good insulators.

(*b*) Overhead lines and apparatus connected with them must be so arranged that they cannot be reached from the ground, roofs, outhouses, windows, or other places open to the public, without special appliances ; at road crossings, especially, they must be kept sufficiently far from the ground or be otherwise protected against contact.

(1) Unprotected overhead lines for high-tension currents must, as a rule, not approach nearer than 6 metres to the ground, and in the case of public roads not nearer than 7 metres.

(*c*) Supports and protective coverings for overhead lines at more than 750 volts to earth must be marked by a red zig-zag arrow.

(*d*) Lines, protective screens and their supports must be sufficiently strong to resist wind pressure and snow loads.

(2) Overhead lines may carry greater currents than indoor ones as long as their mechanical strength is not thereby affected.

(3) For dimensions, etc. of overhead line structures see the "Standards for Overhead Lines," below.

(*e*) According to the nature of the districts traversed, overhead lines, and also the generators, motors, and transformers connected to them, must be suitably protected against lightning. The lightning arresters used must remain operative even after repeated discharges.

(4) When different phases or poles are protected by neighbouring lightning

arresters care must be taken that dangerous voltages are not set up in any ground exposed to traffic because of the position of the earth plates.

(*f*) Overhead high-tension lines must be bare, but where they are liable to be attacked chemically a suitable paint may be used.

(*g*) In the case of overhead lines for over 10,000 volts all iron masts, stay wires, etc., must be well earthed, if necessary by means of an earth wire run parallel to the supply line. Stay wires on wooden poles must either be earthed or provided with reliable strain insulators at points out of reach from the ground.

(*h*) When overhead lines run parallel to other lines or cross them suitable steps must be taken to prevent mutual contact, even in case of a wire breakage, or the contact must be made harmless, or else the whole construction must be carried out with an increased degree of security.

(*i*) When a telephone line is run on the same poles as an overhead high-tension line it must either be arranged so that a dangerous voltage cannot be induced in it or else it must be itself treated as a high-tension line. Telephone exchanges or call offices must be so arranged that even in the event of contact occurring no danger can result to the speaker or operator.

(*k*) When a high-tension line passes over inhabited districts or when it approaches a public road sufficiently closely to involve danger to the passengers should a wire break, the line must either be carried at such a height that if a wire breaks the ends cannot reach within 3 metres of the ground, or else devices must be introduced to prevent the broken wire from falling or to make it dead in the act of falling, or, finally, the whole structure may be carried out with a suitable degree of increased security.

(5) If safety nets are employed with a high-tension line they must be so shaped and situated that contact between them and a wire still intact is impossible and that a broken wire will be caught even if a strong wind is blowing. If the net cannot be definitely earthed it must be well insulated.

(6) At corner points in a high-tension line guard hoops must be employed, which will prevent the falling of the wire if an insulator breaks.

(*l*) It must be possible to make any section of a high-tension line within inhabited districts "dead" if desired.

STANDARDS FOR OVERHEAD LINES.

I. Conductors.

(*a*) *Materials.*

Soft annealed copper wire may only be used for overhead lines if it is not subjected to a greater stress (see (*b*)) than 5 kg. per square millimetre (7,200 lbs. per square inch).

For hard drawn copper wire the maximum stress (see (*b*)) must not exceed 12 kg. per square millimetre (17,200 lbs. per square inch) unless special tests are carried out on the material, in which case a stress amounting to half the elastic limit may be employed. Copper may only be considered as hard drawn if the stress at the elastic limit is at least ·8 of the breaking stress and if the elongation on a length of thirty-five times the diameter amounts to at least 2 per cent. In the case of stranded cables these figures apply to the separate wires.

Hard drawn copper wires may only be soldered at points where they are relieved of all tensile stress.

For aluminium wire a stress of 9 kg. per square millimetre (12,900 lbs. per square inch) is permissible.

When other materials are used the allowable stress must be determined by finding the ratio of elastic limit to breaking stress by tests, and in any case, the working stress must not be allowed to exceed half the elastic limit stress.

(b) *Stress Calculations.*

The stress in the wire is to be calculated first for a temperature of — 20° C. without additional load and then for a temperature of — 5° C. with an additional load due to ice. The weight of ice is to be taken as equal to $\cdot 015 \times q$ kg. per metre run of line, q being the cross-sectional area of the line wire in square millimetres.

In neither of these calculations must the stress work out at more than the limiting values given under (*a*).

II. Poles and Masts.

(a) *Wooden Poles.*

The distances between poles must not exceed the following values :—

Total Cross-Section of all the Lines and Guard Wires.	Length of Span.
105 square millimetres (·164 square inch)	80 metres (260 feet).
105 to 210 square millimetres (·164 to ·328 square inch)	60 metres (196 feet).
210 to 300 square millimetres (·328 to ·465 square inch)	50 metres (163 feet).
Over 300 square millimetres (over ·465 square inch)	40 metres (130 feet).

For these spans the diameter at the top of the poles Z should comply with the following rule :—

$$\text{Diameter of top in cms.} = Z = 1\cdot 2\sqrt{D \times H},$$

where D = sum of the diameters of all the wires on the pole in millimetres,
and H = mean height of the wires above the ground in metres.

Poles of less than 13 centimetres in diameter are not permissible. For high voltages up to 1,000 the minimum allowable diameter is 15 centimetres and for still higher voltages 18 centimetres.

With greater distances between poles than in the above table either the pole diameters must be increased or coupled poles or wooden structures must be used. At curves and at crossings with other electric lines, railways or roads the length of span must be specially shortened to suit the circumstances.

In designing the pole structures in such cases a maximum stress of 70 kg. per square centimetre (1,000 lbs. per square inch) must be allowed.

The maximum wind pressure is to be taken as 125 kg. per square metre of normal effective surface (25·6 lbs. per square foot). In the case of cylindrical bodies the effective surface is to be taken as ·7 times the diameter multiplied by the length.

(*b*) *Wrought-iron Masts.*

The maximum working stress in iron structures is not to exceed 1,500 kg. per square centimetre (21,500 lbs. per square inch).

The most unfavourable case is that occurring with a wind pressure of 125 kg. per square metre of normal effective surface.

For cylindrical surfaces the effective surface area is to be taken as ·7 times the diameter multiplied by the length.

(*c*) *Masts of Special Materials.*

Masts of special material may be loaded up to one-third of the breaking stress guaranteed by the makers. In the case of cast-iron structures the maximum stress is, however, not to exceed 300 kg. per square centimetre (4,300 lbs. per square inch).

(*d*) *Erection of the Masts.*

Poles and masts must be let into the ground to depths depending on their length and on the nature of the soil (in average soil the depth is usually 1·5 to 2·5 metres). The soil must be well punned (in soft soil special precautions may be necessary) and the mast must be specially anchored or strutted at corner points.

In the case of road crossings with high-tension lines a mast must be placed close to the road on each side and falling of the masts must be prevented as far as possible either by their construction or by means of suitable stays or struts.

When both sides of a road are available for mast erection the east side should preferably be chosen, because then the prevalent westerly storms will not be able to blow down the masts across the roadway.

When wooden poles are used in especially stormy districts every fifth mast should, even on straight stretches, be either specially strengthened or provided with stays so as to avoid the likelihood of masts falling on the roadways as far as possible.

III. Special Regulations to be complied with when Safety Nets are to be omitted.

When the use of safety nets is to be avoided by employing specially conservative structures as indicated in § 22 (*h*) and (*k*), the lines must only be subjected to half the stress permitted under I. (*a*). At the same time the masts lying between spans of unequal tensions must be designed to withstand the maximum one-sided pull. By specially shaping the insulators or specially attaching the line wires or by other suitable devices provision must be made so that, in case an insulator breaks, the wire will not fall or will, at least, be earthed before falling.

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